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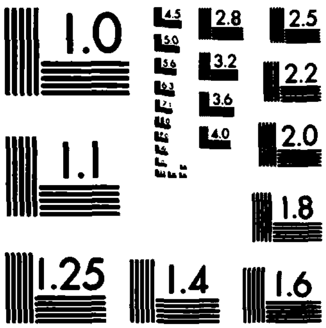

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The Effects of Task Structures, Dynamics of Difficulty Changes, and Strategic Resource Allocation Training on Time-Sharing Performance

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A distinction was made between two aspects of time-sharing performance: time-sharing efficiency and attention allocation optimality. The first one is concerned with the level of joint performance of the time-shared tasks. The second one is concerned with the consistency of protecting the high priority task from variations in the task demand. Time-sharing performance was then evaluated as a function of: (a) the task structures of the component time-shared tasks and (b) the strategic training of resource allocation.

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The secondary task technique was employed. Five pairs of dual task differing in their structural configurations were investigated. The primary task was always a visual/manual tracking task requiring spatial processing. The secondary task was either another tracking task or one of four possible input/~~output~~ configurations of a verbal running memory task. Congruent to a common finding, time-sharing efficiency was observed to decrease with an increasing overlap of resources that the time-shared tasks utilized. Results also tend to support the hypothesis that resource allocation is more optimal when the time-shared tasks placed heavy demand on common processing resources than when they utilize separate resources. The verbal strategy instructions employed to induce more optimal allocation were more successful for the task pairs utilizing common resources than for those utilizing separate resources.

Two significant implications of these results are noteworthy. First, because of the observed tradeoff between time-sharing efficiency and allocation optimality as the structural configurations of the time-shared tasks were varied, task designers need to consider the benefits of time-sharing efficiency as well as those of allocation optimality in making multitask design decisions to optimize system performance. Second, the effects of task structures observed imply that the different processing resources defined by the structure-specific resource model (Wickens, 1980) are not all equally distinct. It appears that the different resources may have different functional properties (e.g., sharability between tasks) and different attention allocation mechanisms.

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The Effects of Task Structures, Dynamics of Difficulty Changes, and Strategic Resource Allocation Training on Time-Sharing Performance

To be able to make intelligent decisions concerning function allocation between the human operator and the machine, we would first need to acquire an understanding of how the processing resources are allocated within the human in a multitask situation. The literature on attention allocation reveals that while the human clearly has some voluntary control of allocation (e.g., Senders, 1964; Moray, Fitter, Ostry, Favreau, & Nagy, 1976), the control is often not optimal (e.g., Brickner & Gopher, 1981), and far from optimal when the task demand changes continuously (e.g., Wickens & Pierce, 1978). Because task demands in many real world environments do fluctuate continuously, it is important to have a good understanding of the nature of this kind of control non-optimality so that its consequences on system performance can be anticipated.

The present paper adopts the view that the control of attention allocation is a cognitive skill (Moray, 1978; Navon & Gopher, 1979). The optimality of such control is to be distinguished from the more familiar term, time-sharing efficiency, which describes the maximum joint performance of the time-shared tasks. Resource allocation optimality is concerned with the consistency of protecting the performance of a high priority task regardless of any difficulty changes. Within the secondary task paradigm, optimal control of attention allocation is such that performance of the primary task remains unaffected by the introduction of the secondary task (Kahneman, 1973). Wickens and Pierce (1978) added the dynamic constraint that as the primary task difficulty increases, an optimal control should draw additional resources from the secondary task if necessary to maintain the primary task performance at a constant level. Further, resources will be reallocated back to the secondary task to maximize its performance when the primary task difficulty has diminished.

Several conclusions can be drawn from the recent studies designed to test the optimality of such a control. First, it is clear that subjects do have voluntary control of attention allocation, though the control is particularly non-optimal with abrupt difficulty changes (e.g., Wickens & Pierce, 1978). Second, the structural configurations of the time-shared tasks appear to be an important factor affecting the level of time-sharing performance. Less task interference was observed when the time-shared tasks were structurally distinct (e.g., Brickner & Gopher, 1981) but the allocation control seemed to be more optimal when the time-shared tasks were similar in structures (e.g., North, 1977; Wickens, Tsang, & Benel, 1979). Third, the allocation behavior is seemingly less optimal when the task demands (levels of difficulty and task priorities) were manipulated continuously within a trial than between trials at discrete levels (e.g., Wickens & Gopher, 1977 vs. Wickens & Tsang, 1979). This would suggest that the allocation of attention may not be a contiuous process but a discrete one in fixed proportion for the duration of the trial. Such a finding casts some questions on Kahneman's assumption that there is a closed feedback loop

between the allocation policy and the process of demand evaluation (Wickens & Tsang, 1979). However, it would be premature to dismiss such an assumption entirely at this point. For example, within the multiple resources framework, such a closed feedback loop may be operative when two tasks compete for the same resources but not otherwise. Fourth, so far, little success has been demonstrated by the conventional training techniques (priority instructions, monetary incentives, on-line performance feedback) to improve resource allocation optimality (see for example, Wickens & Pierce, 1978). Further experimentations will be needed to test whether other forms of training will be more conducive to the improvement of continuous resource allocation.

The central question that the present study addresses is whether the sources of resource allocation non-optimality are due to some structural constraints inherent in the human information processing system or whether they reflect a skill deficiency in resource allocation. The identification of and the distinction between the different sources of non-optimality are not only theoretically interesting, but may also bear important practical implications. For example, while deficiency in a skill can usually be remedied by more effective training, structural limitations can only be minimized by careful task design. Three candidates for the sources of allocation non-optimality are discussed in the present paper.

The first potential source of allocation non-optimality to be considered is suggested by Kahneman's undifferentiated capacity theory (1973). There are two central elements in this theory: the allocation policy and the evaluation of task demands. Through a closed feedback loop between the allocation policy and the process of demand evaluation, attention supplied to the various concurrent activities will vary continuously corresponding to the momentary changes in the demand imposed by the tasks. Kahneman pointed out that the failure to evaluate accurately the discrepancy between task demands and actual performance may be a potential source of allocation non-optimality. However, despite researchers' effort to alleviate the difficulty in the demand evaluation process by, for example, providing subjects on-line performance feedback (Wickens & Pierce, 1978), non-optimality was still observed. However, before dismissing the possibility that the source of non-optimality lies in the demand evaluation process, other potential sources of non-optimality need to be explored and alternative training methods tested.

The second possible source of allocation non-optimality to be considered in the present paper is suggested by the multiple resource theory of attention. This theory is exemplified by Wickens's structure-specific resource model (1980). It is hypothesized in this model that resources can be defined by three dichotomous dimensions related to: (a) the stages of processing (perceptual/central and response processing), (b) the codes of processing (spatial and verbal processing), and (c) the input/output modalities (visual/auditory, manual/speech). In a time-sharing situation, the structure-specific model predicts a tradeoff between the degree of time-sharing efficiency (maximum joint performance) and the optimality of resource allocation

(subject's control of resource allocation according to the demand of the individual simultaneous tasks). The model predicts a greater time-sharing efficiency when the component time-shared tasks place heavy demand on separate resources than when they have to compete for the same resources. This is because not only are there potentially more resources available, there will also be less task interference in the separate resources case. On the other hand, the model predicts that continuous resource allocation may only be possible if the time-shared tasks place heavy demand on at least some common resources; since resources associated with different task structures may not be sharable according to this model. It is therefore hypothesized in the present paper that the level of allocation optimality will increase, but the degree of time-sharing efficiency will decrease, with an increasing degree of resource overlap between the time-shared tasks. This hypothesis will be tested by contrasting the level of allocation optimality and time-sharing efficiency achieveable with five pairs of dual tasks differing in their degree of resource overlap between the component time-shared tasks.

The third potential source of allocation non-optimality to be studied is the failure to apply the appropriate strategy. Welford (1978) hypothesized that there are two stages which are marks of skill. The first stage is the recognition that a possible strategy for performing the task at hand exists. The second stage involves refinement of the strategy used. Singer (1978) asserted that the acquisition of skill can be enhanced by the learning of an appropriate strategy or strategies. Since evidence abounds in the verbal learning and memory literature (e.g., Miller, 1956) demonstrating the effectiveness of strategy training (Baron, 1978), the present study will explore the appropriateness of verbal strategy instructions on the training of the skill of attention allocation.

Experimental Approach

To examine the various potential sources of allocation non-optimality discussed above, the secondary task technique will be used in the present research. One of the two component time-shared tasks is assigned a high priority and designated as the primary task. The other task is assigned a low priority and is called the secondary task. When the primary task is time-shared with the secondary task, the primary task performance is to be kept at the same level as its single task performance. Then the difference in the secondary task performance between the single- and dual-task conditions is taken as an index of the workload imposed by the pirmary task (see Kerr, 1973; Ogden, Levine, & Eisner, 1979; Rolfe, 1971).

The present study will adopt the experimental approach (Kantowitz & Knight, 1976) commonly employed in the attention allocation studies. The relative resource demand of the time-shared tasks will be manipulated by: (1) changing the task priorities by means of payoffs or instructions, and (2) varying the difficulty level of the primary task (Gopher & Navon, 1980). The underlying rationale for these manipulations is as follows. As the priority or the difficulty level of the primary task increases, additional resources will have to be

invested in the primary task in order to maintain its performance at a constant level. In the situation where the primary and secondary tasks must compete for the same resources, the secondary task performance will inevitably deteriorate because of its decreased share of resources; given that the maximum available capacity is already being deployed.

Although the discrete manipulation of the relative use of resources between trials is a more conventional practice (e.g., Gopher & Navon, 1980), the present study will employ a continuous difficulty manipulation within a trial. There are two reasons for employing a continuous manipulation. First, task demands in many real world environments do vary dynamically (e.g., in the driving and flying environments). Second, the attention allocation literature reveals that subjects are particularly non-optimal when task demand changes continuously (e.g., Wickens & Pierce, 1978).

Also, two structurally different pairs of dual-tasks will be investigated. Both pairs have a compensatory tracking task as the primary task whose difficulty varies continuously within a trial. One of the pairs has a compensatory tracking task with constant difficulty, the other pair has a discrete short-term memory task as the secondary task. The tracking task is chosen because of its continuous nature which allows not only continuous manipulation of task demand but also fine-grained time-series analysis on the tracking performance. The discrete short-term memory task, on the other hand, allows examination of the speed-accuracy tradeoff in the secondary task performance in response to the changes in task demands. The structural characteristics of the tracking and memory tasks are described below.

Structural compositions of the time-shared tasks. Although the tracking task clearly requires perception of the error signals, it is considered to impose the greatest demand upon the responding stage (Israel, Chesney, Wickens, & Donchin, 1980). While the short-term memory task requires selection and execution of discrete responses as well, it presumably places the heaviest demand on the central processing stage. A second dimension along which the tracking and memory tasks differ is the processing codes: spatial processing for the tracking task and verbal processing for the memory task. Thus, the dual-tracking task pair is structurally similar, whereas the memory-tracking task pair imposes heavy demands on separate codes and stages. In addition, the effects of the various input and output modalities combinations on time-sharing performance will also be investigated. Four variations of the short-term memory task consisting of all possible combinations of two input modalities (visual and auditory) and two response modalities (manual and speech) will be used in the experiment. The various structrual configurations to be investigated then define an ordered continuum of degrees of shared resources betwen the time-shared tasks, placing the tracking-tracking pair on one extreme and the tracking-audio/speech memory pair on the other.

The purpose of the structural manipulation is to test the possibility that the allocation non-optimality observed in the literature is at least partially structure-related. The level of

allocation optimality is expected to be higher for the dual-tracking configuration than for the memory-tracking configurations. Among the four memory-tracking variations, attention allocation is expected to be more optimal between the task pair that has common input/output modalities (both visual-manual) than the other three with non-identical I/O modalities. Attention allocation between the memory-tracking pair that employs completely separate input/output modalities (visual-manual for one and audio-speech for another) is expected to be least optimal.

Strategy training. Because strategy training has been found to improve many cognitive skills (Rigney, 1978), it is hypothesized here that strategy instructions can improve the skill of attention allocation. In the present experiment, two independent groups of subjects will be used to assess the effectiveness of strategy training in improving resource allocation optimality. Only one group will receive verbal strategy instructions. The effectiveness of the strategy instructions on resource allocation optimality will be tested in two ways: (1) comparison of group performances, (2) examination of the transfer of training to a new task situation. Allocation optimality is expected to improve for those subjects receiving strategy instructions. Subjects in the strategy instructions group are also expected to be better able to transfer their allocation ability to the new task situation than those in the no strategy instructions group.

Time-sharing performance analysis. Time-sharing performance is typically assessed by some average scores over a trial (e.g., Root Mean Square tracking error). The degree of time-sharing efficiency will be reflected by the extent of task interference and the level of allocation optimality by the constancy of the primary task performance. To capture the moment by moment performance changes in response to the continuously changing task demands, Wickens and Pierce (1978) have used time-series analysis (e.g., see Chatfield, 1973) to assess the attention allocation optimality. The rationale for using this technique is as follows. If the primary task performance is protected successfully, it will not vary with the difficulty fluctuations. Correlation between the primary task difficulty variation and performance should therefore be small. To the extent that the primary and secondary tasks utilize the same resources, resources are to be withdrawn from and replaced to the secondary task as the primary task difficulty changes, causing the secondary task performance to fluctuate with the difficulty changes. Therefore, the correlation between the primary task difficulty and the secondary task performance should be high. In time-series analysis, the correlation between two time-series (a performance series and a series of the time-varying difficulty function) is given by the linear coherence measures. This coherence measure is analogous to the square of the usual correlation coefficient, having values in the range of 0 - 1. In the present context, optimal resource allocation will be reflected by low coherence measures between the primary task performance and its difficulty variation and high coherence mesasures between the secondary task performance and the primary task difficulty variation. The reverse will be an indication of allocation non-optimality.

Method

Subjects

Twenty right-handed male students from the University of Illinois, ages 19-30, were divided equally between the augmented feedback and the strategy feedback groups. Subjects were paid for the first seven sessions on an hourly basis. Thereafter, each subject's pay was based on a monetary bonus system.

Tasks

A secondary task technique was employed. Two dual-task configurations were chosen. The primary task in both configurations was a compensatory tracking task. This tracking task was paired with either another compensatory tracking task or a running short-term memory task. The primary task difficulty was time-varying whereas the secondary task difficulty was fixed at a constant value throughout the trial (200 sec). Primary tasks were performed by the right hand and manual secondary tasks were performed by the left.

Tracking task (TR). The one-dimensonal compensatory tracking task was displayed on a 10.2 by 7.6 cm screen of a Hewlett-Parkard Model 1330a CRT. The tracking display was driven by a band-limited Gaussian disturbance input with an upper cutoff frequency of .32 Hz. The cursor moved in a lateral direction. Control of the cursor was achieved by lateral deflection of a Measurement System Incorporated Model 435 spring-centered control stick. The difficulty parameter of this task was the order of the system control dynamics (alpha) whose value ranged from 0 (pure velocity) to 1 (pure accelaration). The system control dynamics and the system output were governed by a PDP-11/40 computer.

The secondary task alpha was fixed at a value of .5. The primary task time-varying difficulty function (200 sec) was made up of a series of ramp functions between the value of 0 and 1. The slopes of these ramps were defined by two rates of difficulty changes (10 sec and 20 sec) between the minimum and maximum alpha values. Four different time-varying functions were generated to reduce the predictability of the task. Each time-varying function was comprised of a random ordering of the following: four 10-sec zero slopes at maximum alpha value, four 10-sec zero slopes at minimum alpha value, two 10-sec positive slopes (alpha increased from 0 to 1), two 10-sec negative slopes (alpha decreased from 1 to 0), two 20-sec postive slopes, and two 20-sec negative slopes.

Tracking error was sampled every 50 msec. A Root Mean Square Error (RMSE) was computed every second. Two hundred running averages of RMSEs were obtained using a 2-sec sliding window. Than an overall average RMSE was calculated for each trial.

Short-term memory task (STM). The input of this task was a sequence of random digits between 1 and 9 presented one at a time. Subjects were to respond by recalling the digit 1-back or 2-back. Four variations of this self-paced running memory task employing a combination of the various input modalities (visual and auditory) and response modalities

(manual and speech) were used. The visually presented memory tasks (VM, VS) were displayed at the center of the same CRT upon which the tracking task was displayed. The auditory memory tasks (AM, AS) were presented monoaurally through headphones to the left ear. Each visual digit was displayed for 1 sec. Each auditory digit had a duration of 375 msec. A new digit was presented 1.5 sec after the initiation of response to the previous digit. The maximum ISI for the dual-task conditions was determined individually for each subject to ensure that the memory task remained self-paced and yet could not be ignored indefinitely. Speech responses (for the VS and AS conditions) were spoken into a microphone mounted on a headset and were processed by a Centigram Mike-2 recognition unit. Manual responses (for the VM and AM conditions) were made by pressing the appropriate response buttons. Performance measures included accuracy (percent error) and average reaction time (RT).

Dual task. In the dual-tracking condition (TR-TR), the two tracking tasks were displayed separately with a slight lateral offset, having a visual angle of approximately one degree. In the memory-tracking conditions (STM-TR), the input of the VM and VS tasks were presented at the center of the screen and the tracking display was centered towards the bottom of the screen.

To ensure that resource allocation would not be impeded by the lack of immediate feedback, leading to the failure in evaluating the momentary task demands, on-line performance feedback in the form of warning symbols were presented whenever the subject's performance was poorer than the predetermined standard. Performance standards were obtained for each subject individually for each different condition. For the dual-tracking condition, the subject's best single task performance of the variable alpha condition was used as his performance standard for the primary task in the dual-tracking condition. The primary task warning symbol (*) was presented on the right, beside the tracking display whenever the intergrated RMSE (averaged over a sliding 5-sec window) was higher than the standard. For the memory-tracking conditions, a combined speed-accuracy score was established as the performance standard by adding the average reaction time (in seconds) and the proportion of errors over the last five digits presented. Since each error made would augment the combined score by .2 (one error out of five digits), the warning symbol was highly sensitive to accuracy. Such an algorithm was chosen to discourage subjects from pressing the response buttons mindlessly in order to earn the RT bonus. The warning symbol (*) was presented on the left of the stimuli digit whenever the running average of the combined performance score was poorer than the standard. The warning symbol remained on the screen as long as performance was poorer than the standard. The duration and the cancellaton latency of every warning signal displayed was recorded for the primary task and the secondary task independently.

Design

A mixed design was employed with two independent groups of subjects receiving different amounts of instructions but otherwise performing the same tasks for 11 sessions. The two groups were: the augmented feedback group (AF) and the strategy feedback (SF) group. The

AF group was run before the SF group. Both groups received average performance feedback (average tracking RMSE, average reaction time and number of errors for the memory task) at the end of each trial. Both groups received on-line performance feedback and monetary bonus starting with Session 8 when the priority instructions were first introduced.

The major purposes of each of the eleven sessions are summarized here. The first five sessions were single-task training, followed by two sessions of dual-task training. Extensive single-task and dual-task training were included to attain stabilized performance before introducing the major experimental manipulations. Primary task performance standard (best single-task level) were established at the end of Session 5. Secondary task performance were also established to ensure that subjects would not abandon the secondary task entirely and perform the primary task singly. The secondary task standard was the best secondary task performance obtained by the end of Session 7. The priority instructions, warning symbols, and bonus system were introduced during Session 8. Subjects performed the same tasks for the following two sessions with the exception that the SF group received additional strategy instructions at the beginning of those sessions. Lastly, the secondary task difficulty was increased in Session 11.

Procedure

With the exception of Sessions 5 and 7, where the order of all the tasks were randomized for each subject, the same general task sequence was followed by all subjects. The order of appearance of the four STM tasks was randomized for each session. The time-varying function used was randomly chosen for each time-varying difficulty trial. In the dual-task sessions, the TR-TR tasks and the STM-TR tasks were performed on separate blocks. The order of appearance of these two blocks was counterbalanced across sessions.

Session 1 - Single tracking. Subjects performed the constant difficulty tracking tasks at three alpha levels (0, .5, and 1) with each hand and then the variable difficulty tracking with the right hand only. Subjects were to keep their tracking RMS error as low as possible.

Session 2 - Single STM with 1-digit back. The session began by familiarizing the subjects with the voice recognition unit. Training consisted of repeating the nine digits four times and tested for recognition twice. The voice pattern templates of each subject were stored to be used for the remaining of the experiment. The voice training was repeated periodically throughout the experiment whenever the recognition percentage dropped below 90. After voice training, subjects performed each of the memory tasks with a speech response (VS, AS) three times and each of those with a manual response (VM, AM) twice by recalling the numbers 1-digit back. Subjects were instructed to respond as fast and as accurate as possible but accuracy was emphasized to be more important than speed.

Session 3 - Single STM with 2-digit back. Subjects first performed each of the four STM tasks with 1-digit back once, then, each of the four STM tasks with 2-digit back twice.

Session 4 - Single tracking. Same as Session 1.

Session 5 - All single tasks. After two tracking practice trials, subjects performed each possible single-task condition once in a random order. Primary task performance standard was established from the subject's own best single-task performance for each task condition.

Session 6 - Dual tasks. Dual tasks were first introduced in this session. Subjects were to perform both tasks as well as possible. Subjects performed the dual-tracking condition twice, then performed each of the four memory-tracking conditions once with 1-digit back (VM1-TRV, AM1-TRV, VS1-TRV, AS1-TRV) and once with 2-digit back (VM2-TRV, AM2-TRV, VS2-TRV, AS2-TRV).

Session 7 - All dual tasks. After four single-task practice trials, each dual-task condition was performed once in a random order. Secondary task performance standard was established from the subject's own best secondary task performance in each of the dual-task conditions.

Session 8 - Priority instructions. Several new manipulations were introduced in this session. First, the secondary task paradigm was adopted. Instead of trying to perform both time-shared tasks as well as possible, subjects were asked to consider their right hand task to be the Primary Task, that is, a high priority task. The left hand tracking or the memory task was to be considered as the Secondary Task, that is, a low priority task. Subjects were asked to maintain a constant performance of the primary task at the single-task performance level regardless of the difficulty level. It was suggested to the subjects that at the instances that the primary task was difficult (alpha = 1), more attention should be devoted to the primary task. But when the primary task difficulty had diminished, subjects were to reallocate their attention to the secondary task so as to maximize the secondary task performance as well.

The second major manipulation of this session involved the introduction of the monetary bonus system. The bonus system served as an incentive for the subjects to adhere to the priority instructions as closely as possible. To encourage subjects to maintain a constant primary task performance, they would be able to earn 50 cents for every trial that their primary task RMSE was within +/- .01 of their best single-task RMSE. Subjects only received 35 cents for the trials that their primary task RMSE was within +/- .02 of their standard and nothing otherwise. Everytime that the subjects were able to break their own secondary task performance record, they received a small additional bonus (15 cents). This latter provision was included to ensure that subjects were deploying their maximum resources should they have any spare capacity after the primary task criterion was met.

The third new manipulation involved the display of warning symbols whenever the subject's performance was poorer than his standard. Warning symbols were provided to help the subject to better evaluate his momentary performance against the desired standard level.

After three single-task practice trials, subjects performed two dual tracking with the secondary task alpha at .5 and each of the four 1-digit back STM-TR conditions once.

Session 9 - Strategy feedback. Strategy instructions were provided for the SF group at the beginning of the session; procedure was otherwise the same as Session 8. The strategy feedback entailed showing the subjects the on-off pattern of the warning symbols of the primary and secondary tasks for each trial obtained in the previous session when the priority instructions were introduced. Portions of the pattern where the primary task warning symbol remained on for a long period of time and the secondary task warning symbol was not, were pointed out to the subjects as indication of insufficient resource allocating. Portions where the primary task warning symbol was cancelled shortly after the onset of the secondary task warning symbol were identified as the optimum form of behavior.

All the subjects in the SF group were informed of the "optimal" strategy. Based on the performance and strategy reports of the subjects in the AF group (see Results section), the SF group was instructed to adopt different strategies as the situation demanded. Given the different task configurations in the various dual-task conditions and the time-varying primary task difficulty, subjects were asked to experiment with their strategies within a trial as well as between different task pairs.

Session 10 - Practice with priority and strategy instructions. Procedure was the same as the previous session. This session provided subjects further practice with their allocation skill. Subjects in the SF group who were still unable to keep their primary task performance at the standard level were constantly encouraged to employ the strategies provided.

Session 11 - Increased secondary task difficulty. The secondary task tracking alpha was increased from .5 to 1, and subjects were to perform the memory task with 2-digit back instead of 1-digit back. If resource allocation was optimal, the primary task performance should not be affected by this increase in the secondary task difficulty. Only the secondary task perfomance was expected to deteriorate.

Results

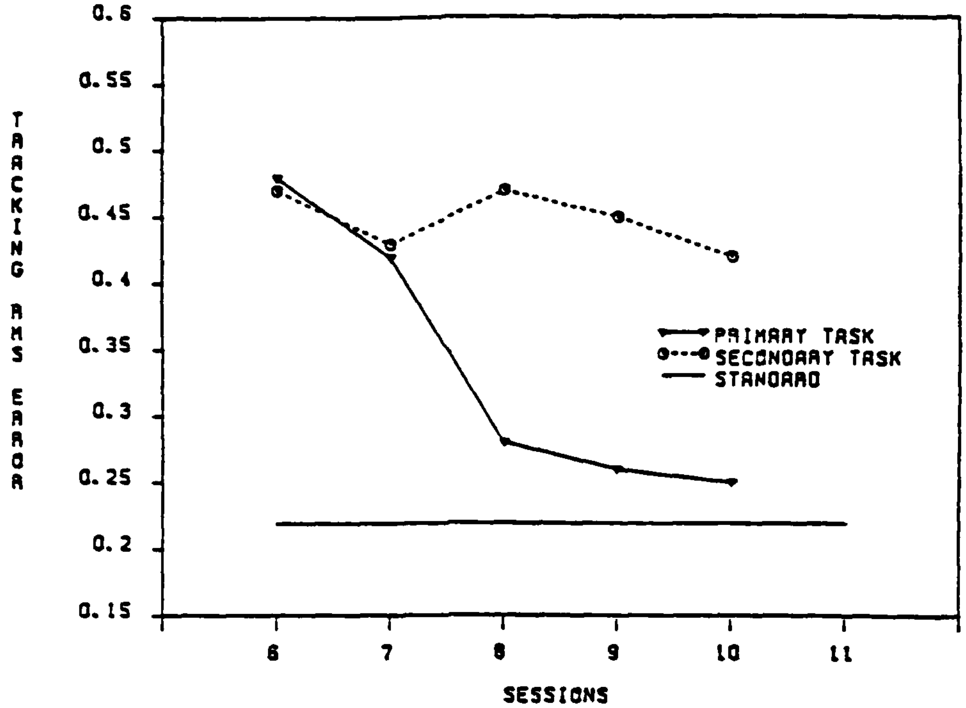
The structural effects on resource allocation will be examined first. Then the effectiveness of the strategy instructions on improving attention allocation optimality will be discussed. Single-task performance had stabilized before the dual-task conditions were introduced in Session 6. The data presented here are mainly dual task performance measures obtained under the four major phases of the experiment: (1) before the priority instructions were introduced (Sessions 6 and 7), (2) when the priority instructions were first introduced (Session 8), (3) during practice with the priority and strategy instructions (Sessions 9 and 10), and (4) with increased secondary task difficulty.

Effects of Task Structures on Dynamic Allocation

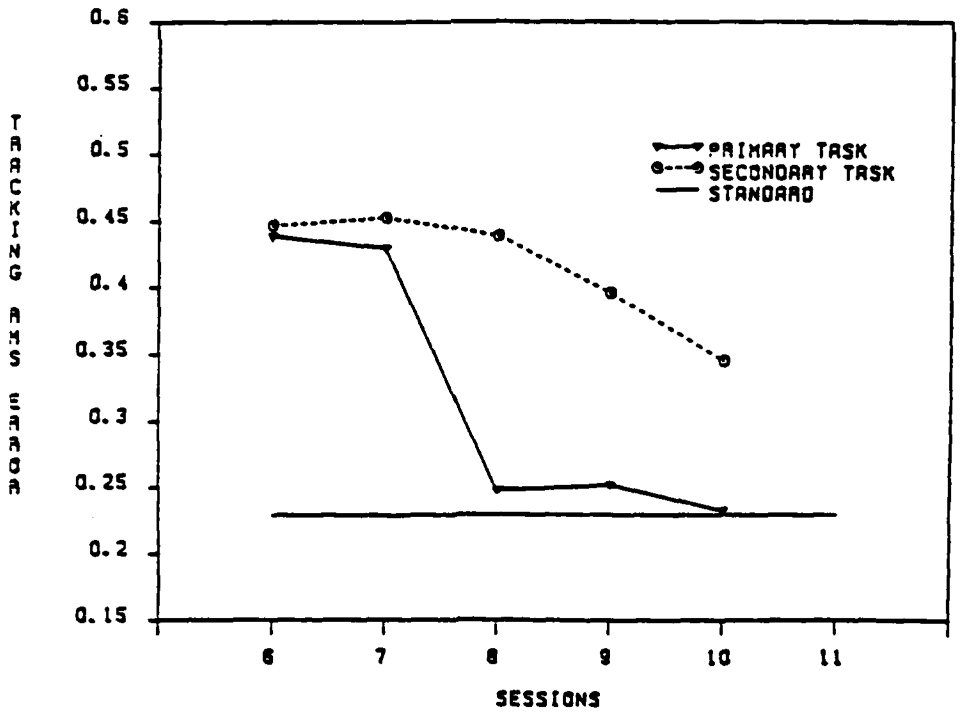
All five dual tasks had the same time-varying difficulty primary task. The five secondary tasks had varying degrees of overlapping resources with the primary task in terms of: (1) the stages/codes of processing (between the TR-TR and STM-TR pairs), (2) the I/O modalities (among the four variations of the STM-TR pairs). Allocation optimality was assessed in two ways: (1) by the subject's ability to maintain an average primary task performance at the standard level, and (2) by the subject's ability to guard the moment by moment primary task performance against difficulty changes. The former was measured by the average performance over a trial (RMSE scores for tracking, RT and percent error for the memory task). The latter was measured by the linear coherence measures obtained from time-series analyses performed on the moment by moment tracking error ensemble averages (over subjects).

TR-TR. The effects of the priority instructions first introduced in Session 8 are clearly portrayed in the average RMSE plotted in Figure 1 ((a) for the AF group and (b) for the SF group). Before the priority instructions were introduced (Sessions 6 and 7), the levels of the primary and secondary task errors were almost indiscriminable. With the introduction of the priority instructions in Session 8, the primary task error dropped drastically and remained fairly close to the average standard for both groups of subjects (.22 for the AF group and .23 for the SF group as indicated by the horizontal line on the figures). In fact, the SF group actually reached the desired primary task standard by Session 10 (Figure 1b). In contrast, the secondary task error for the AF group even increased slightly with the priority instructions before declining gradually for the remaining sessions. The Task (primary vs. secondary) x Session interactions were significant at .01 level for both groups (AF: $F(4, 36) = 18.97$, SF: $F(4, 36) = 9.64$). Although the secondary task error eventually decreased as well, the decrease was much smaller than that of the primary task, showing that subjects were voluntarily allocating more resources to the primary task than the secondary task in response to the priority instructions. The continual, though slight, decrease in the secondary task error suggests that, with practice, only sufficient resources were allocated to the primary task and spare resources were utilized to improve the secondary task performance.

Ensemble averages of the running RMSE obtained in Session 7 (before the priority instructions were introduced) showed that the primary and secondary task errors were at about the same level, but the peaks and the valleys of the primary task error fluctuations were slightly larger than those of the secondary task. With the introduction of the priority instructions in Session 8 (Figure 2), the separation between the primary and secondary task errors became more apparent (as portrayed in Figure 1). The secondary task error appeared to fluctuate much more vigorously in Session 8 than the previous session, even though its difficulty was constant throughout these sessions. The ensemble averages obtained in Session 10 showed a further decrease in both the primary and secondary task errors after more practice with the priority instructions. The peaks and valleys of the primary task fluctuations were also reduced.

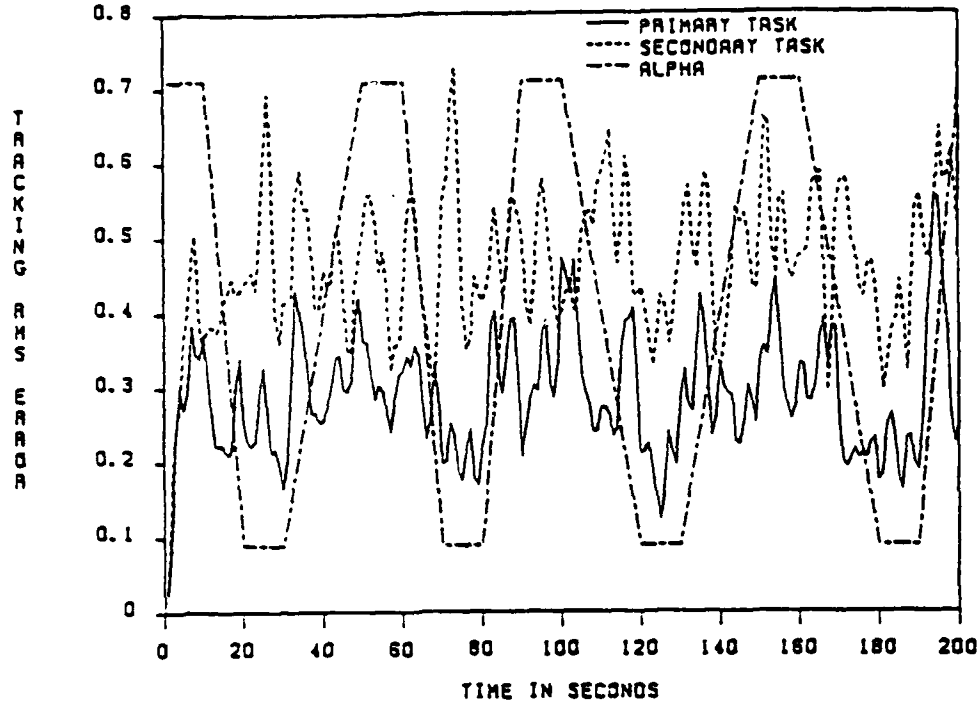


(a) AF Group

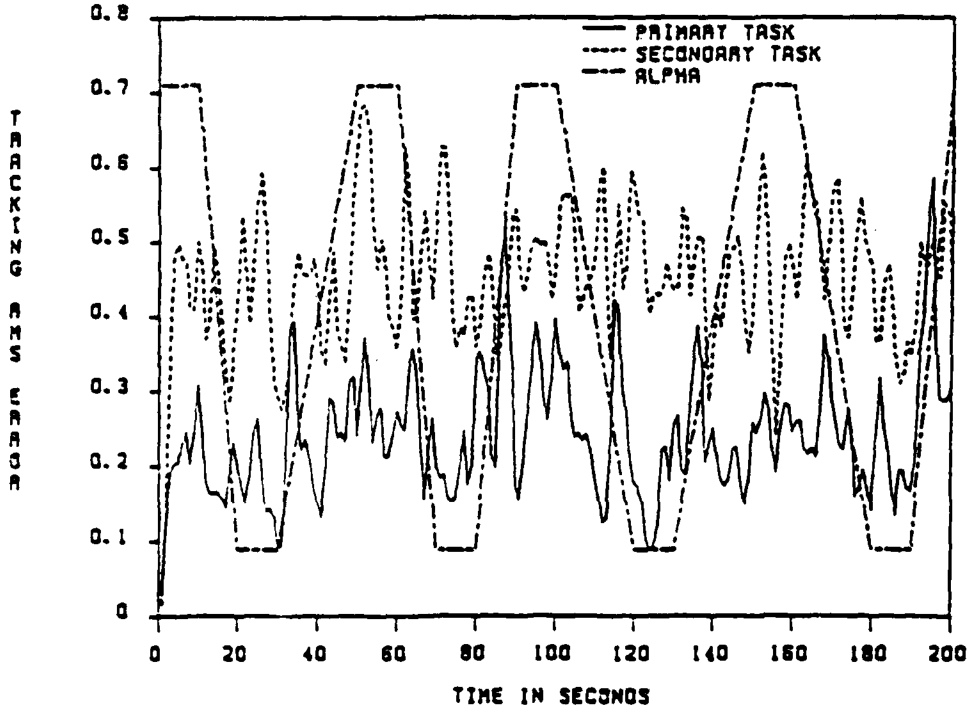


(b) SF Group

Figure 1: Dual-task tracking performance.



(a) AF Group



(b) SF Group

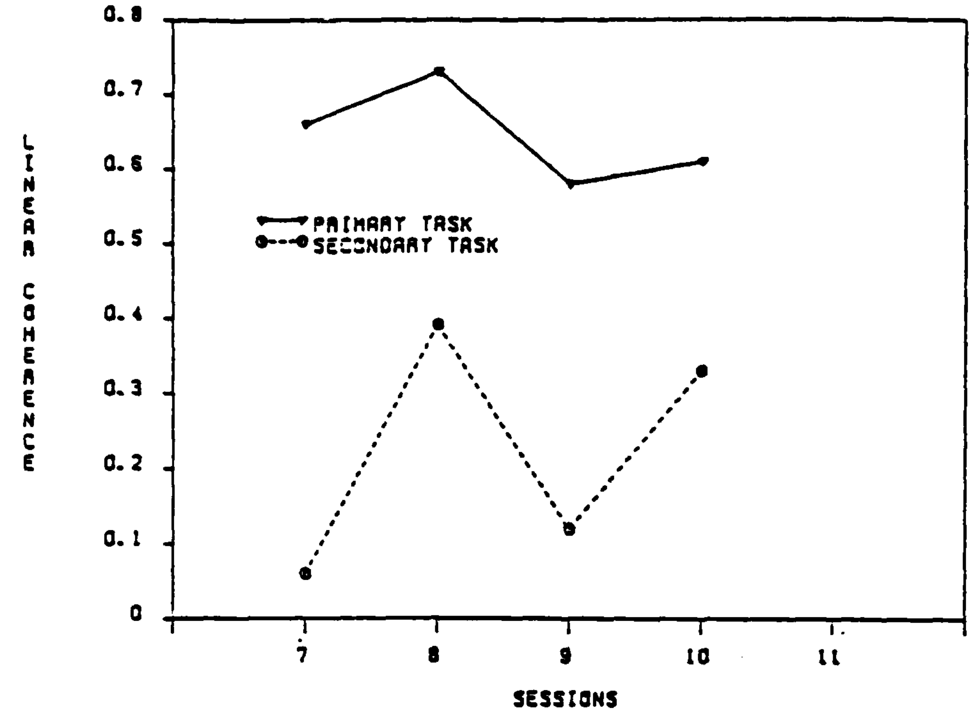
Figure 2: Dual-tracking ensemble averages obtained in Session 8 when the priority instructions were first introduced.

Linear coherence measures obtained from the ensemble averages such as those presented in Figure 2 are displayed in Figure 3. Time-series analyses for bivariate series (program BMD-02T) were performed to obtain the coherence measures between the difficulty function and ensemble tracking error. A mean of the coherence measures obtained at the three frequencies with the highest density estimate for the alpha function was obtained. In the sessions that had more than one trial of the same task, the mean coherence measure obtained from each trial were again averaged over trials before it was plotted in Figure 3.

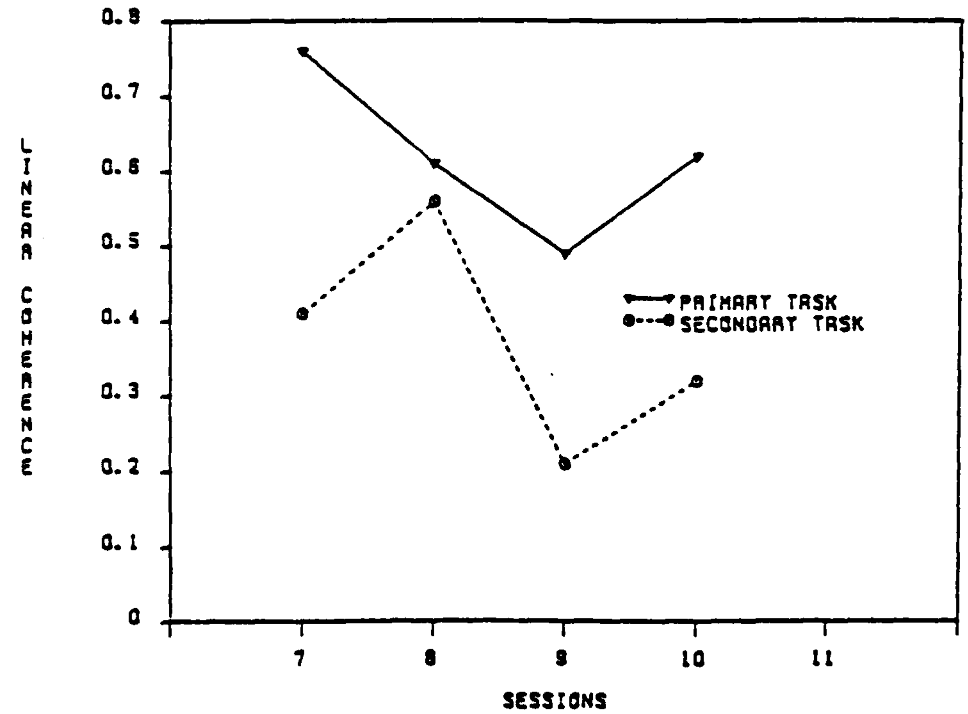
Upon learning the priority instructions in Session 8, the SF group (Figure 3b) appeared to behave in the direction predicted for optimal allocation. The primary task coherence measures decreased and the secondary task coherence measures simultaneously increased from Session 7 to Session 8. The increase in the secondary task coherence measures suggest an increase in the secondary task performance variability, time-locked to the primary task difficulty, even though the secondary task difficulty was fixed at a constant level. Although the primary task coherence measures for the AF group (Figure 3a) did not decrease in Session 8 as predicted by the optimal model, its increase was slight compared to that of the secondary task. Unfortunately, since all the coherence measures were obtained from ensemble averages, no error terms were available to test statistically the interaction between the primary and secondary tasks.

Though a change in resource mobilization between the primary and secondary tasks in response to the priority instructions was evident, resource allocation could not be characterizaed as optimal. First, the primary task coherence measures were considerably higher than those of the single task (average around .4) throughout the dual task sessions. This finding shows that the moment by moment primary task performance was not as consistently protected against the difficulty variations as the single task performance, despite the fact that the average primary task performance was quite close to the standard (Figure 1). Second, contrary to the optimality prediction, the primary task coherence measures remained consistently higher than those of the secondary task for both groups of subjects (Figure 3). In short, the linear coherence measures show that resource allocation even for this structurally similar task pair was not optimal. Resource allocation between the structurally dissimilar task pairs is expected to be even less optimal.

<u>STM-TR</u>. The average primary task RMSEs for all five pairs of dual task are plotted in Figure 4. The average primary task standard was the same for all dual tasks since they all had the same primary task: dual tasks: .22 for the AF group and .23 for the SF group (indicated by the horizontal line on Figure 4). The primary task of all four STM-TR pairs responded to the priority instructions in a manner similar to that of the TR-TR pair. A two-way ANOVA (Session x Task) indicates that the session main effect was significant for both groups of subjects (AF: $\underline{F}$ (4, 36) = 104.76, SF: $\underline{F}$ (4, 36) = 26.93; $\underline{p}$ < .01). The task main effect was also significant (AF: $\underline{F}$ (4, 36) = 20.01, SF: $\underline{F}$ (4, 36) = 17.48; $\underline{p}$ < .01). When data from the priority sessions only (Sessions 8-10) were analyzed, the task main effect remained significant (AF: $\underline{F}$ (4, 36) =

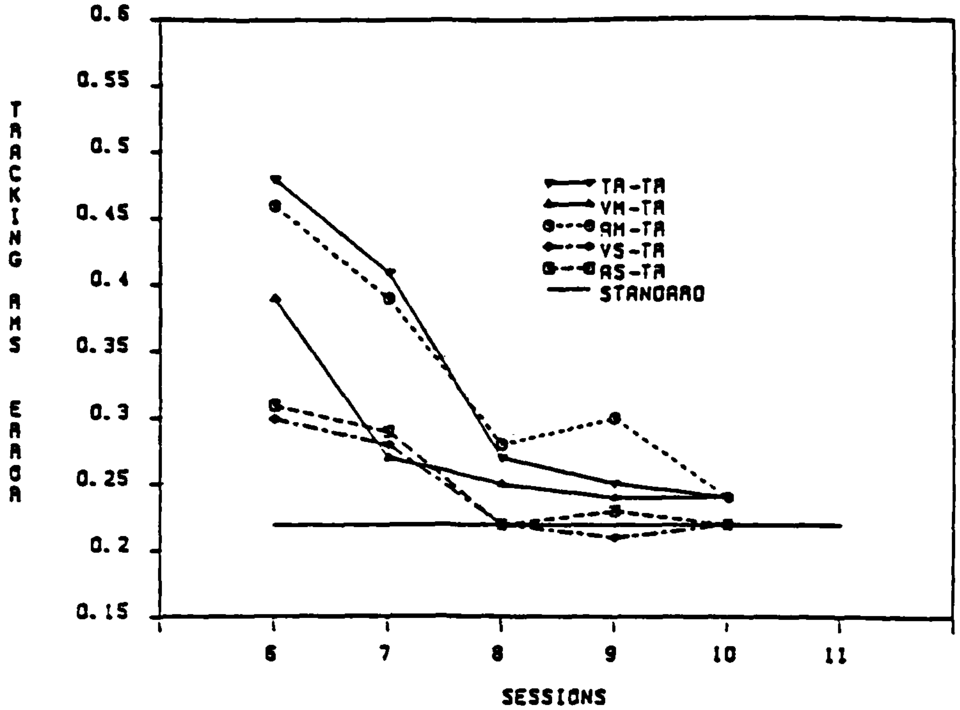


(a) AF Group

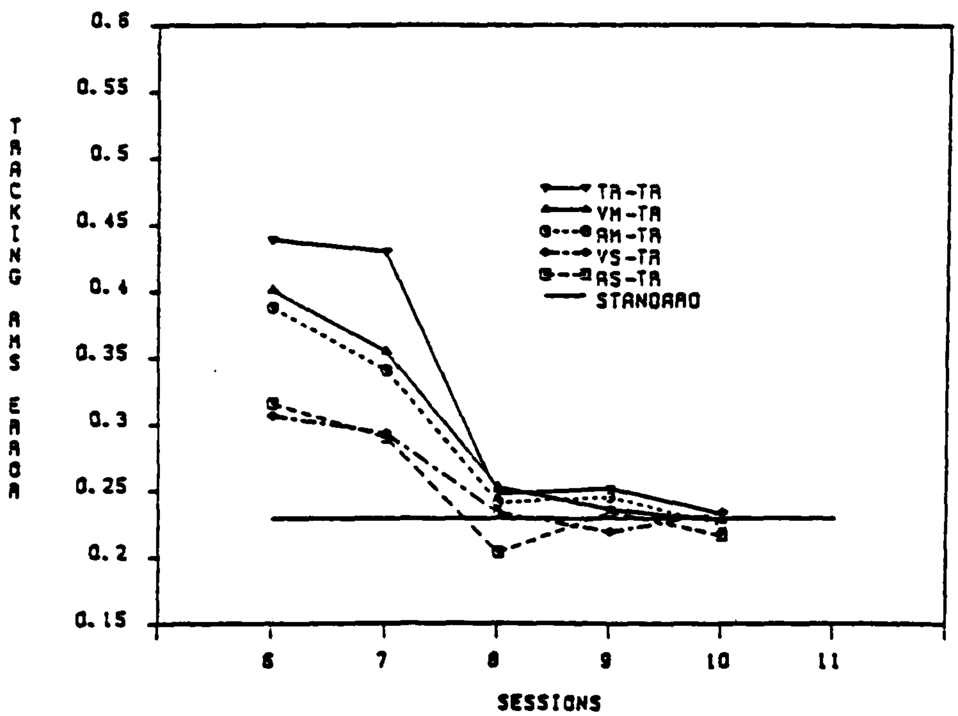


(b) SF Group

Figure 3: Dual-tracking linear coherence measures obtained between the tracking error and primary task difficulty.



(a) AF Group



(b) SF Group

Figure 4: Primary task tracking performance of five structurally different task pairs.

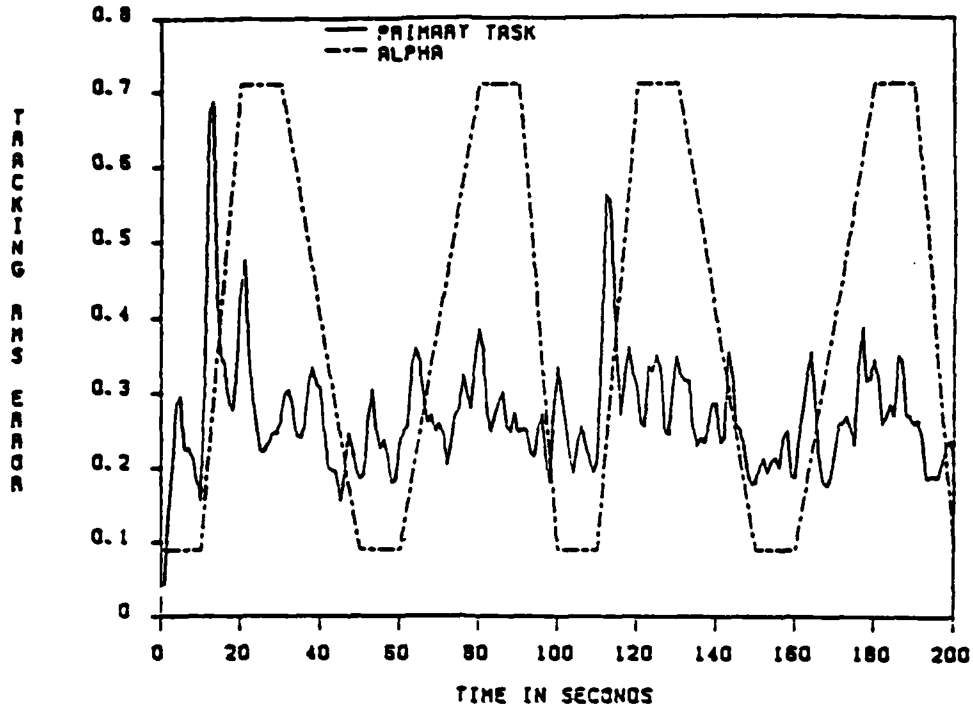
8.88, $p < .01$; SF: $F(4, 36) = 3.60$, $p < .02$). Thus, post hoc pairwise comparisons (Scheffe) were performed on the the last three sessions data.

For the AF group, the TR, VM, and AM conditions were not significantly different from each other ($p > .05$). However, these three conditions, all of which employed a manual secondary response, had significantly higher error than the two conditions employing a speech secondary response (VS and AS) with $p < .05$. The only significant pairwise difference obtained for the SF group was between the TR and AS conditions ($p < .05$). These results are in general agreement with the structure-specific resource model's prediction that there will be a greater degree of task interference between time-shared tasks that place heavy demand on the same resources (output modalities).

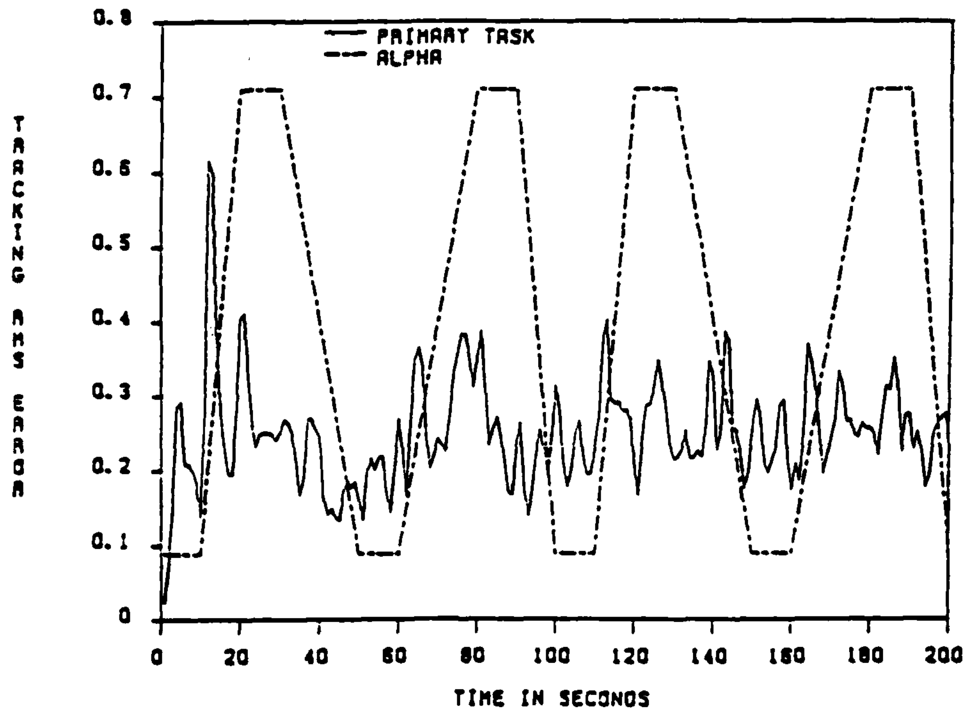
To further test the interaction between the input and output modalities, data for the four STM-TR tasks from the last three sessions were analyzed in the next four-way ANOVA (Session x Group x Input x Output). The session main effect was significant ($F(2, 36) = 7.04$, $p < .01$), but the group main effect was not ($p > .60$). The input main effect (visual vs. auditory) was not significant ($p > .20$), but the output main effect (manual vs. speech) was reliable ($F(1, 18) = 23.34$, $p < .01$). Results from this last ANOVA together with those from the pairwise comparisons show that the degree of task interference between the time-shared tasks depends not only on the number of shared resources but also on the particular common resources utilized by the time-shared tasks. Although the AM and VS memory tasks each has one I/O modality in common with the tracking task, the primary task error of the AM condition was found to be higher than that of the VS condition (significantly so for the AF group). Since tracking places the greatest demand on the response resources, it is not surprising that the effects of output competition were more pronounced than those of input competition (Wickens, Sandry, & Vidulich, 1983).

Primary task ensemble averages for each of the four STM-TR conditions were obtained when the priority instructions were first introduced (Session 8) and after more practice with the priority instructions (Session 10). Because of the similarity in the patterns of the ensemble averages between the two STM-TR pairs that employed a secondary manual task, only the VM-TR is displayed in Figure 5. Likewise, because of the similarity in the ensemble patterns between the two speech STM-TR conditions, only the AS-TR is displayed in Figure 6. Due to the discrete nature of the secondary task performance measures (RT and percent error), no ensemble averages or coherence measures were obtained for the memory task.

Although the primary task was the same for all pairs of dual tasks, sharp primary task error spikes were found present at the onset of the primary task difficulty increases in the STM-TR ensembles (Figures 5 and 6) but not in the TR-TR ensembles (Figure 2) when the priority instructions were first introduced. After some practice with the priority instructions, the error spikes seem to have disappeared for those STM-TR pairs employing a manual secondary response (Figure 7) but not for those employing a speech secondary response.

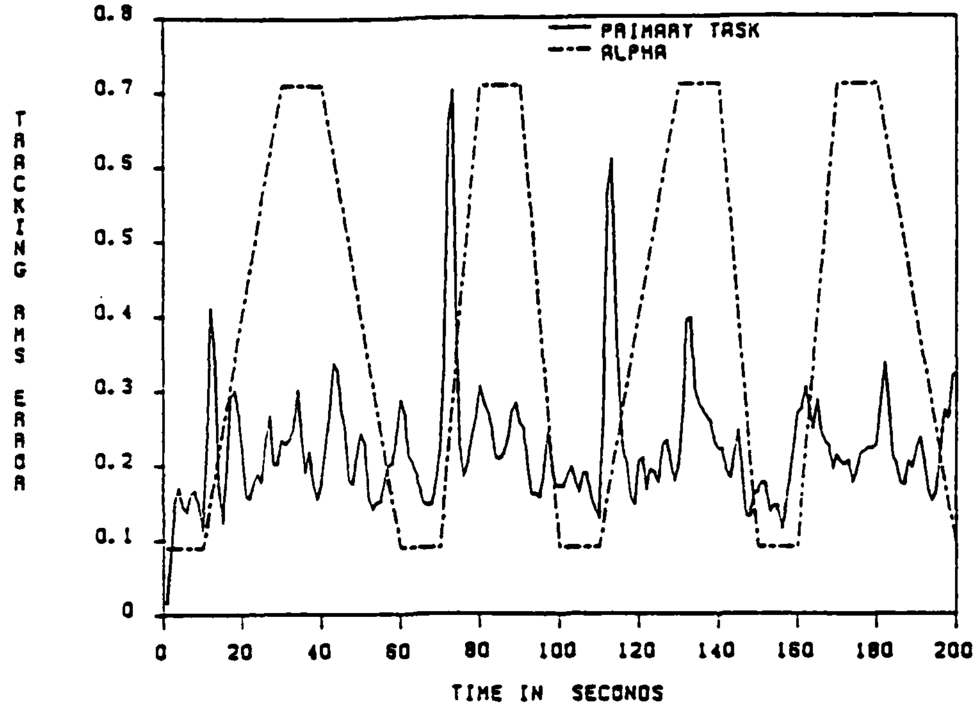


(a) AF Group



(b) SF Group

Figure 5: Primary task ensemble averages of VM-TR obtained in Session 8 when the priority instructions were first introduced.



(a) AF Group

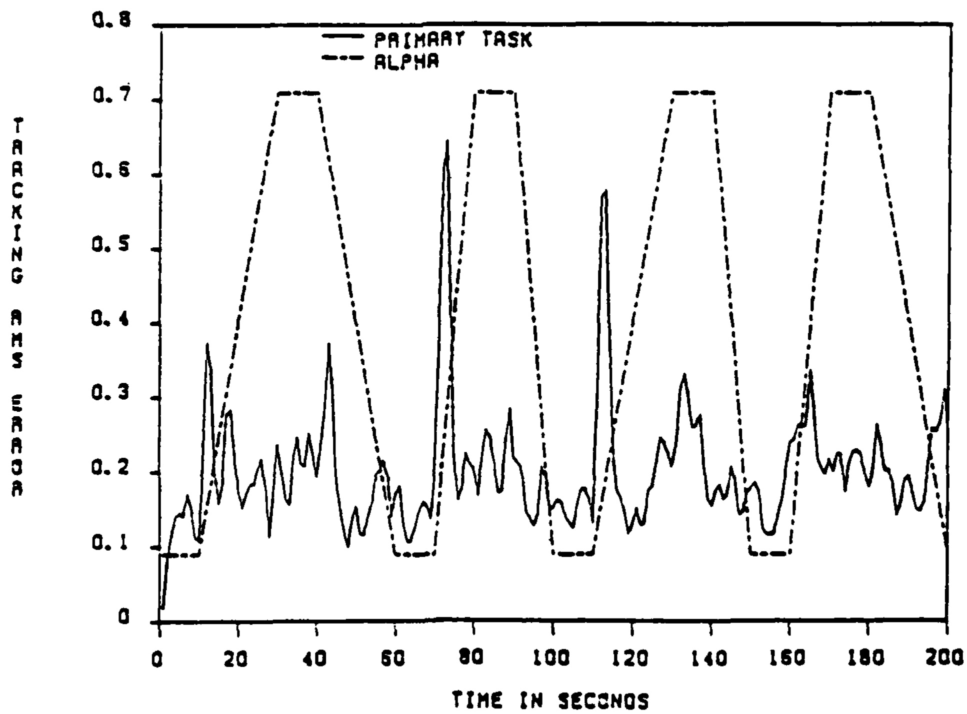


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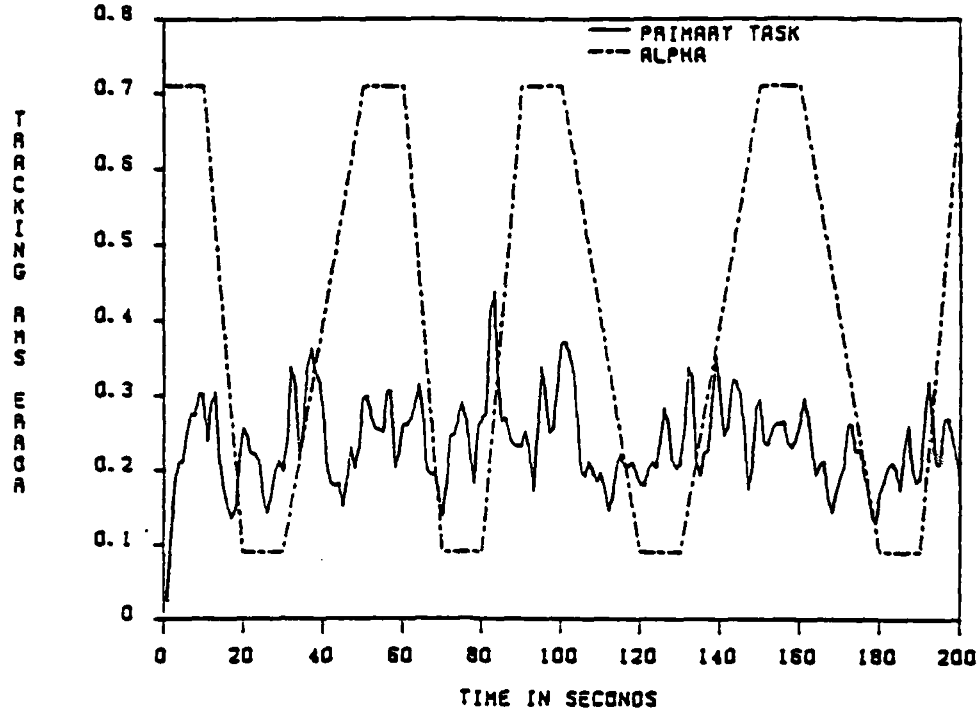
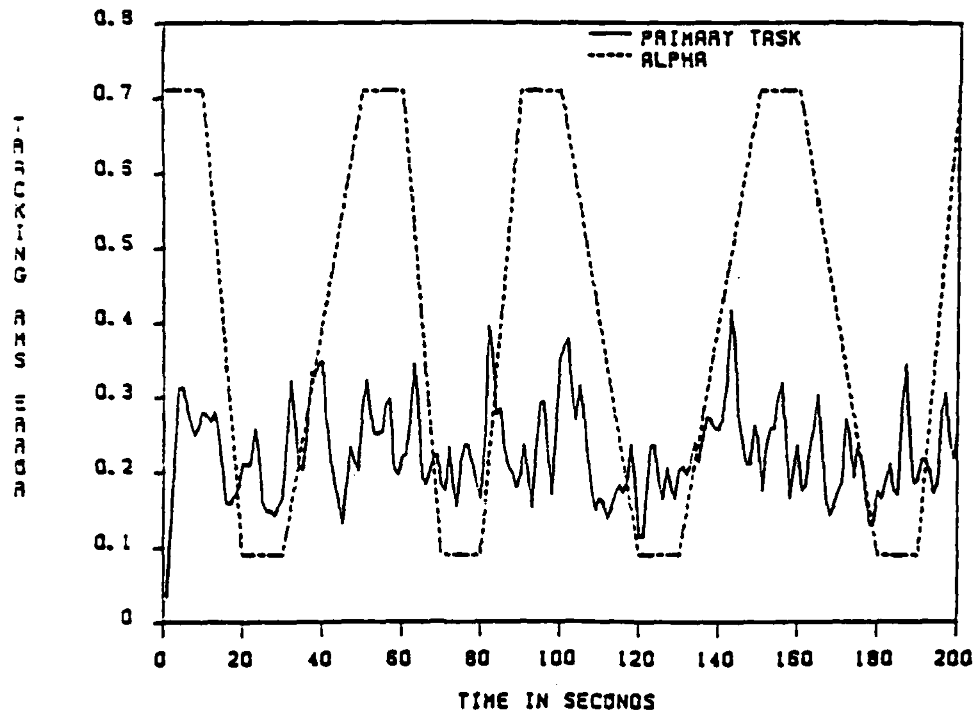
Figure 6: Primary task ensemble averages of AS-TR obtained in Session 8 when the priority instructions were first introduced.



(a) AF Group



(b) SF Group

Figure 7: Primary task ensemble averages of VM-TR obtained in Session 10 after some practice with the priority instructions.

To examine the error spikes data in a more quantitative fashion, the amplitude of a spike at each of the four rising slopes of the alpha function (two 10-sec and two 20-sec slopes) was estimated by subtracting the value of the tracking error at the base of the spike from that at the peak of the spike. Measures obtained for both groups of subjects (four from each group, making a total of eight replications) for each STM-TR condition were analyzed by two ANOVAs. The mean spike amplitudes obtained at Sessions 8 and 10 are plotted in Figure 8. It appears that the magnitude of the error spikes could be ordered by the degree of non-overlapping resources between the time-shared tasks. This is particularly so early in practice with the priority instructions. Figure 8 shows that the structurally identical task pair (TR-TR) has the smallest error spikes early in practice and the pair with separate stages/codes, but the same I/O modalities (VM-TR) has the next smallest error spikes. Then the pairs with separate stages/codes and either separate input or separate output modalities (AM-TR or VS-TR) have spikes of moderate magnitude. Finally, the error spikes are the largest for the task pair with separate stages/codes and separate I/O modalities (AS-TR). After some practice with the priority instructions (Session 10), the amplitude of the error spikes for the two manual response pairs was much reduced indicating subjects' improved ability to guard their primary task performance against momentary difficulty increases in these conditions. The magnitude of the error spikes of those STM-TR pairs with separate output modalities on the other hand remained large reflecting subjects' failure in protecting their primary task performance from the difficulty increases even by the end of the experiment. Two ANOVAs were conducted to test these observations.

The first two-way ANOVA (Session x Task) tested the practice effect and the difference between the five task pairs. The session main effect was not significant but the task main effect was reliable at .01 level ($\underline{F}$ (4, 28) = 3.88). Post hoc comparisions (Scheffe) show that the spike amplitudes (collapsed over sessions) for the AS condition were significantly larger than those for the VM condition at .10 level. The rest of the pairwise comparisions were not reliably different.

The second ANOVA (Session x Input x Output) examined the effects of the input/output modalities configurations of the STM-TR tasks. Results showed that the two input modalities were not significantly different from each other ($\underline{p} > .10$) but the two output modalities were reliably different ($\underline{F}$ (1, 7) = 12.63, $\underline{p} < .01$). The Session x Output interaction was also significant ($\underline{F}$ (1, 7) = 10.24, $\underline{p} < .02$), confirming the observation that the error spikes obtained in the VM and AM ensembles in Session 8 were much reduced by Session 10, but the spikes in the VS and AS ensembles were unchanged by practice.

The linear coherence measures obtained between the primary task ensemble errors and the difficulty function of the STM-TR tasks are plotted in Figure 9. Unlike the primary task coherence measures of the TR-TR pair which eventually decreased after some practice with the priority instructions, a net increase in the primary task coherence measures was obtained for almost all of the STM-TR pairs from Session 7 to Session 10.

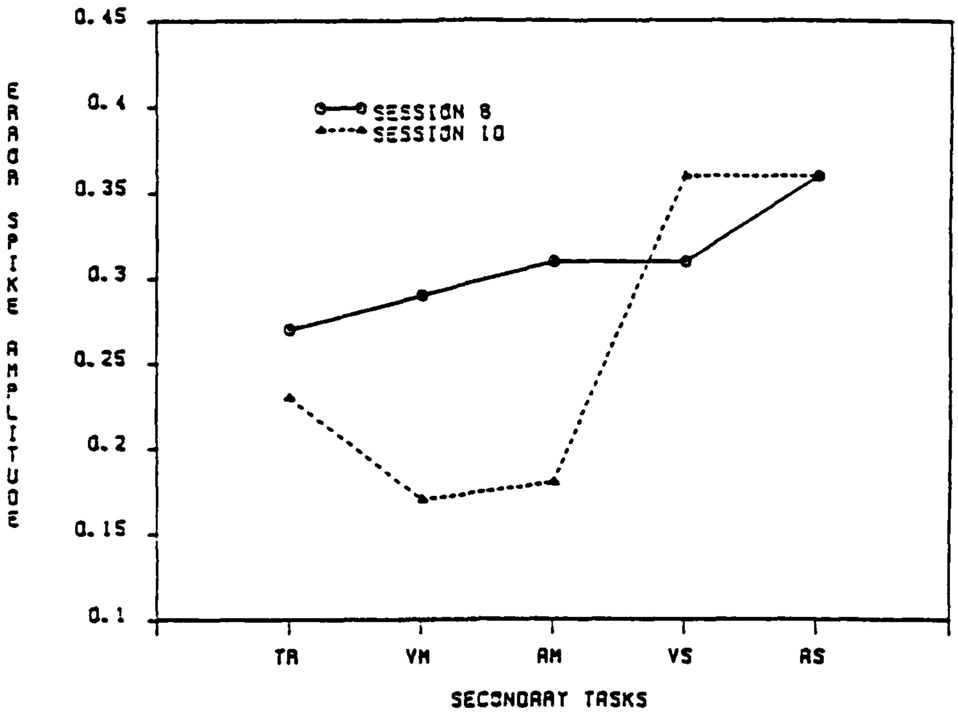
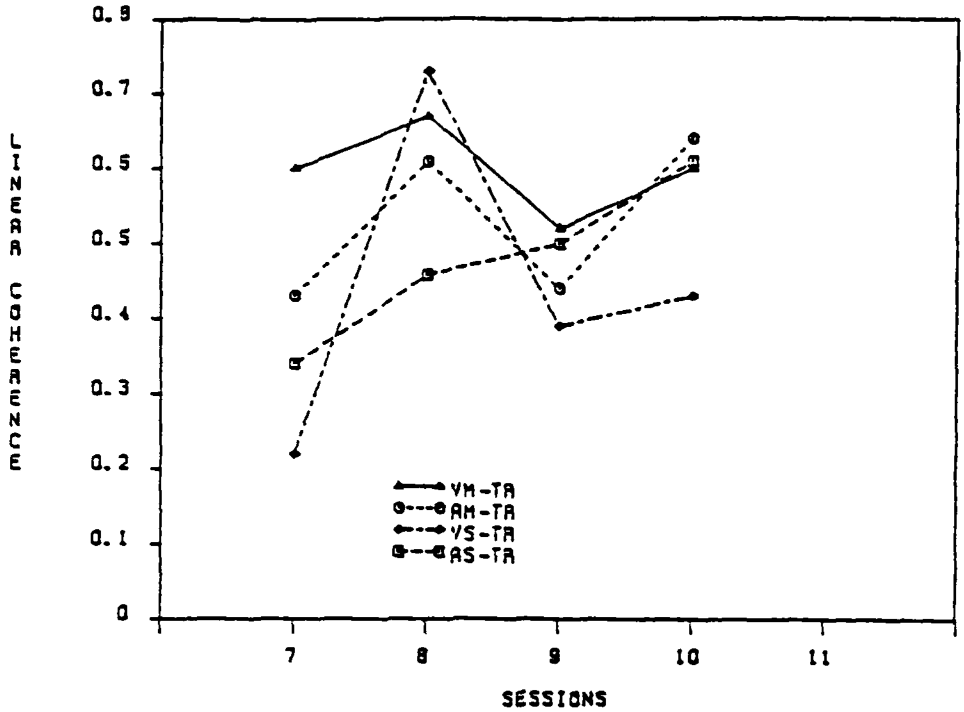


Figure 8: Error spikes amplitude (in RMSE) observed in the primary task ensemble averages of five structurally different task pairs.



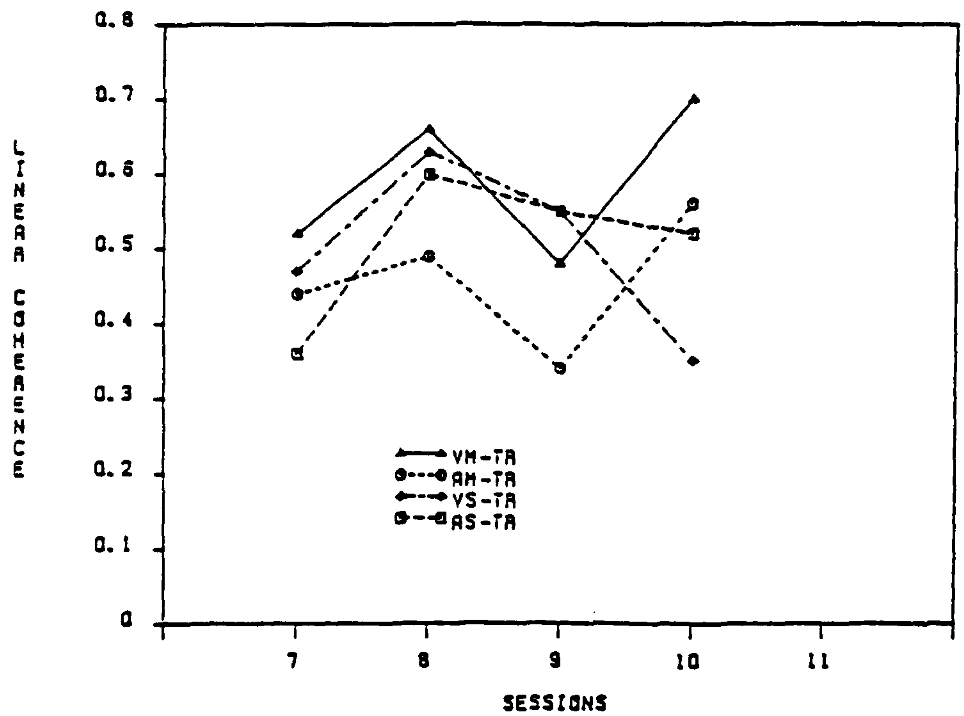
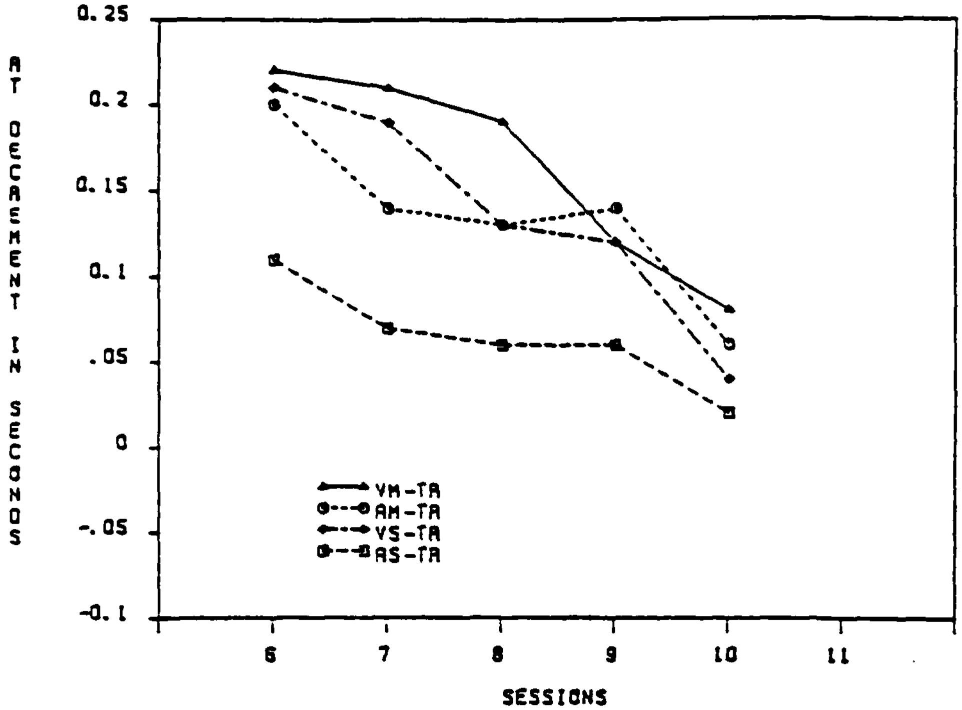


Figure 9: Memory-tracking linear coherence measures obtained between the primary task tracking error and difficulty function.

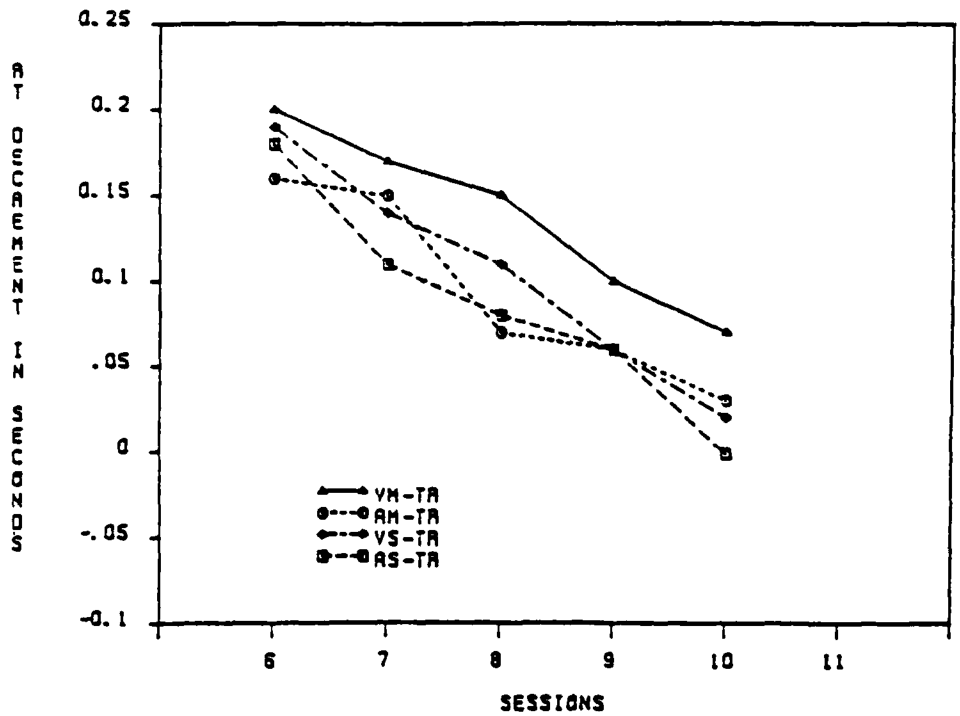
Secondary task performance measures for the STM-TR conditions consisted of RT and percent error. Figure 10 shows that the RT decrements continued to decrease through the dual-task sessions. RT decrement scores instead of the RT data were examined here to eliminate the RT difference between the manual and speech responses that was due to the processing delay of the voice recognition unit. A two-way ANOVA (Session x I/O) shows that the session main effect was significant for both groups of subjects (AF: $\underline{F}$ (4, 36) = 18.71, SF: $\underline{F}$ (4, 36) = 13.39; $\underline{p}$ < .01). The I/O main effect was not reliable for either group (AF: $\underline{F}$ (3, 27) = 2.64, $\underline{p}$ > .07, SF: $\underline{F}$ (3, 27) = 1.11; $\underline{p}$ > .1).

Data of the last three sessions from the two groups of subjects were combined and the I/O effects separated in the next ANOVA (Session x Group x Input x Output). The session main effect was still significant at .01 level ($\underline{F}$ (2, 36) = 30.52). By Session 10, there was practically no RT decrement in the AS condition for the AF group and even a slight RT improvement for the SF group. The groups were not reliably different ($\underline{p}$ > .1). The input main effect was significant at .06 level ($\underline{F}$ (1, 18) = 4.21). The output main effect was not signigicant ($\underline{F}$ (1, 18) = 2.91, $\underline{p}$ = .11). The Session x Input interaction was significant at .05 level ($\underline{F}$ (2, 36) = 3.72) but the Session x Output interaction was not reliable ($\underline{p}$ > .1). As portrayed in Figure 10, the RT decrements for the visual conditions were in general larger than those for the auditory conditions during the early dual task sessions. But, by the last session, the magnitude of the RT decrements for the four I/O conditions appeared in the exact order predicted by the structure-specific resource model. The VM task had the greatest degree of shared resources with the tracking task and the greatest degree of task interference was observed between this task pair. The AS task had the least common resources with the tracking task and had the smallest RT decrement. The AM and VS tasks each had one I/O modality in common with the tracking task and their RT decrements were found to be in between the VM and AS conditions.

The error spikes observed in the primary task ensemble averages of the STM-TR tasks prompted a closer examination of the secondary task performance in the instances that the primary task error spikes occured. Presumably, the error spikes were a result of not having sufficient resources available for the primary task. There are two possible causes for this: either resources were not withdrawn from the secondary task, or resources were withdrawn from the secondary task but were not delivered to the primary task. If resources were not withdrawn from the secondary task at all, the RT data would not vary with the primary task difficulty changes. On the other hand, if resources were withdrawn from the secondary task, but just could not be delivered to the primary task, the RTs should increaes with the primary task difficulty increaes. Thus, the mean RTs over a small interval before and during the primary task difficulty increases were examined. There were four rising slopes in each of the difficulty functions but only the two with the sharpest primary task error spikes were analyzed. The rising slope was divided into two phases: 10 sec before the rise of the slope, and 10 sec (or 20 sec) during the slope. Since the primary task error spikes were generally more prominent as well as more persistent in the speech than



(a) AF Group



(b) SF Group

Figure 10: Memory-tracking secondary task reaction time decrement.

the manual conditions, RTs obtained in Session 10 were subjected to a Phase x Output two-way ANOVA. RTs obtained at each phase of the slope were averaged over the two chosen slopes, over groups, and over subjects.

RTs obtained for the manual and speech conditions before (Phase I) and during (Phase II) the increasing difficulty slope are plotted in Figure 11. RTs indeed were found to increase as the primary task difficulty increased, suggesting that some resources were withdrawn from the secondary task when the primary task was difficult. The phase main effect was significant at .05 level (F (1, 19) = 5.73, p < .03). The speech RTs were significantly slower than the manual RTs (F (1, 19) = 62.19, p < .01), but this difference was at least partly due to the mechanical constraint of the voice recognition unit. However, the Phase x Output interaction was not reliable (F (1, 19) = 0.49, p > .1). Since the RTs increased in both the speech and manual conditions, it does not appear that the sharp primary task error spikes which remained in the speech but not the manual conditions towards the end of the experiment were due to subject's not trying to allocate his resources. Alternative explanations for the magnitude difference in the primary task error spikes between the speech and manual conditions will be explored in the Discussion section.

Accuracy performance of the STM-TR conditions were also examined. A two-way ANOVA (Session x I/O) for each group of subjects shows that there was no significant accuracy decrement from the single- to dual-task conditions (session main effect was not significant, p > .05). Thus, the RT decrements portrayed in Figure 10 were not due to a speed-accuracy tradeoff. The I/O main effect was not significant for either group (p > .2).

Summary. A summary of the structural effects on time-sharing efficiency and resource allocation optimality is presented in Table 1. In this table, the five pairs of dual task are ordered in a decreasing degree of shared resources between the time-shared tasks. The resource-defining dimensions are listed across the page on the left. Resources common to both time-shared tasks are marked by an "X". The structural effects on time-sharing efficiency As predicted by the structure-specific resource model, the degree of task interference was found to be directly related to the degree of shared resources between the time-shared tasks. The post hoc comparisons of the primary task performance of five pairs of dual task show that those pairs with dual manual responses had higher error than those pairs with a manual primary and a speech secondary response (see Figure 4). The magnitude of the RT decrement scores for the four pairs of STM-TR task were also in the same order as the degree of shared resources between the time-shared tasks by the end of the experiment (see Figure 10). Hence, time-sharing efficiency -- an inverse of task interference, was depicted to have an inverse relationship with the degree of shared resources between the time-shared tasks in Table 1.

The level of allocation optimality, on the other hand, has a direct relationship with the degree of shared resources between the time-shared

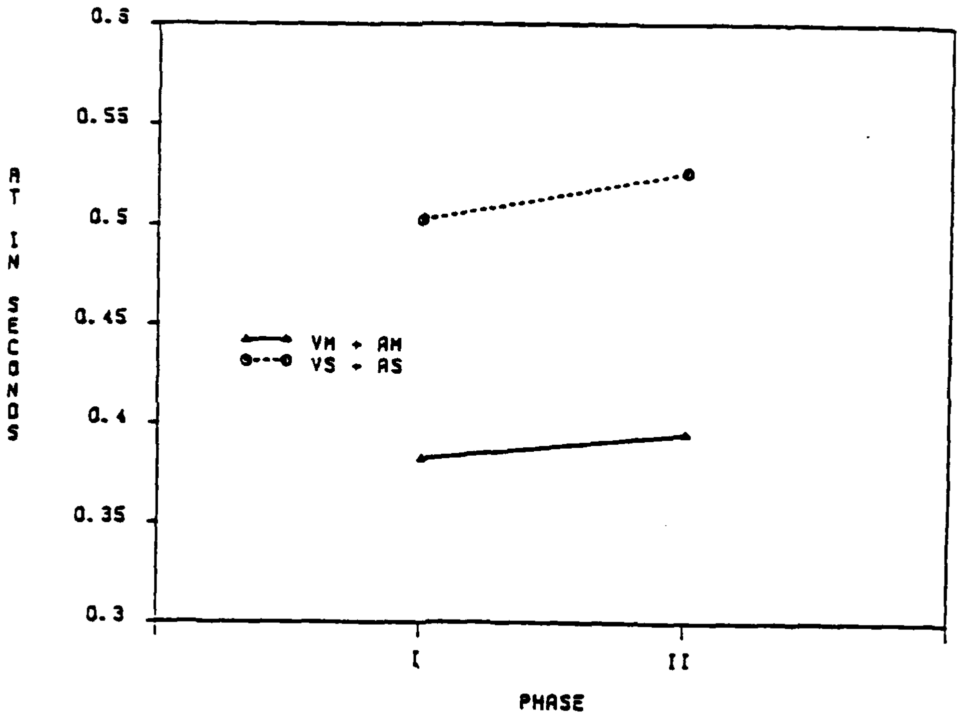


Figure 11: Reaction time obtained within the intervals of 10 sec before (Phase I) and 10 (or 20) sec during (Phase II) the rising slope of the primary task difficulty function.

Table 1

Summary Effects of Task Structures on Time-Sharing Efficiency and Allocation Optimality

Degree of Shared Resources	Tasks	Processing Structures: Processing Stage	Processing Structures: Processing Code	Processing Structures: Input Modalities	Processing Structures: Output Modalities	Measures of Optimality: Time-sharing Efficiency	Measures of Optimality: Allocation Optimality: Coherence	Measures of Optimality: Allocation Optimality: Spikes
High	TR-TR	X	X	X	X	Low	High	High
	VM-TR			X	X		Low	Medium[1]
	AM-TR				X			
	VS-TR			X				
Low	AS-TR					High		Low

[1]Medium = allocation optimality improves with practice.

tasks. Firstly, subjects were quite able to maintain their average primary task tracking performance at the standard level in both the TR-TR and STM-TR conditions (see Figure 4). The secondary task performance also improved slightly for both conditions (Figures 4 and 10), but the extent of the improvement did not reach that of the primary task. The differential response to the priority instructions observed in the primary and secondary tasks suggests that subjects were voluntarily allocating more resources to the primary task. Secondly, a net decrease in the primary task coherence measures was observed in the identically structured TR-TR condition for both groups of subjects (Figure 3). In contrast, the primary task coherence measures for the structurally dissimilar STM-TR tasks were not reduced for either group (Figure 9). Thirdly, the different ensembles patterns obtained between the TR-TR and the STM-TR conditions suggest that even though subjects were able to maintain their average primary task performance at the standard level under both conditions, the manner by which this goal was achieved could be quite different for the different task pairs. This observation was further supported by the results of the spike analyses (Figure 8).

Increased Secondary Task Difficulty

The ability to protect the primary task performance despite the difficulty increase in the low priority task with no previous priority instructions practice would indicate that resource allocation is a skill which, once learned, can be transferred to a new situation.

TR-TR. Results show that subjects were indeed able to maintain their average primary task performance at the standard level despite the the secondary task difficulty increase. As in the easier dual-tracking condition (Figure 1), there was a large decrease in the primary task error but a relatively stable secondary task performance in response to the priority instructions. A three-way ANOVA was performed contrasting groups and primary/secondary task over sessions (Session x Group x Task). No reliable difference was found between groups (F (1, 18) = 0.39, p > .05). The main session effect (F (2, 36) = 65.78), the main task effect (F (1, 18) = 93.72), and the Session x Task interaction (F (2, 36) = 27.61) were all reliable at .01 level. A decrease in the primary task coherence measures was also observed as in the easier dual-tracking condition. There was even a more pronounced decreasing trend of the primary task and increasing trend of the secondary task coherence measures, suggesting that the degree of allocation optimality had not been reduced in this more difficult secondary task condition.

STM-TR. In contrast to the results observed under the dual-tracking condition, subjects were not able to reduce the primary task coherence measures of the memory-tracking conditions when the secondary task difficulty was increased. Results resembled those of the easier STM-TR conditions (Figure 9). The ability to maintain the average primary task performance at the desired standard level however was not greatly impaired by the increase of the secondary task difficulty. The primary task error for all five pairs of difficult dual tasks were subjected to a three-way ANOVA (Session x Group x Task). There were no reliable group differences. The improvement over sessions was significant (F (2, 36) = 97.07, p < .01). A reliable difference was also obtained

among the five tasks (F (4, 72) 55.66, $p < .01$). The Session x Task interaction was significant at .01 level (F (8, 144) = 16.26). Resembling the results obtained from the five easier dual tasks (Figure 4), those STM2-TRV conditions with a manual secondary task generally had higher errors than those with a speech secondary task. Scheffe post hoc comparisons showed that the primary task RMSE of the TR-TR condition was significantly higher than that of the STM-TR conditions at .05 level. The RMSEs of the VM and AM conditions were not reliably different from each other, neither were the RMSEs of the VS and AS conditions ($p >$ .05). The RMSEs of both manual conditions were however significantly higher than those of both speech conditions ($p < .05$).

Like their easier counterparts (Figure 10), the RT decrement scores in Session 11 for all four I/O conditions were decreased from the pre-instructions sessions. A three-way ANOVA (Session x Group x I/O) indicates that there was no reliable group difference, a significant I/O main effect (F (3, 54) = 8.52, $p < .01$), and a significant RT improvement at .01 level (F (2, 36) = 18.88). When the error data (from both the single- and dual-task conditions) were analyzed (Session x Group x I/O), the I/O effect was significant (F (3, 5) = 7.19, $p <$ .01), the error increase was not (session main effect, $p > .1$), showing again that the RT decrements were not a result of a speed-accuracy tradeoff. Consistent with the structure-specific resource model prediction, those STM2-TRV conditions having the maximum common I/O modality resources with the primary task (VM2-TRV) again had the highest error for both groups of subjects. No reliable group difference or significant interaction were obtained.

<u>Summary</u>. Results show that subjects were quite capable of maintaining the average primary task performance at the standard level in spite of the increased secondary task difficulty. The degree of allocation optimality appeared to be comparable to that observed under the easier conditions for both the TR-TR and STM-TR taasks. Since subjects had no prior practice with the priority instructions under the increased secondary task difficulty condition, their primary task performance improvement suggests a case of successful transfer of learning from the easier conditions, providing further support for the claim that resource allocation is a skill and is a trainable one.

<u>Effectiveness of Strategy Feedback</u>

In the present experiment, an optimal control would be indicated by an average primary task RMSE that was equal or close to the standard RMSE and a primary task error that fluctuated little with the difficulty changes (low coherence). Based on these two criteria, each subject in the AF group was categorized according to whether his primary task RMSE was within +/- .02 of his standard and whether his primary task coherence decreased (+) or increased (-) with the following three manipulations: (i) priority instructions (from Session 7 to Session 8), (ii) practice with the priority instructions (from Session 8 to Session 10), and (iii) increased secondary task difficulty (from Session 7 to Session 11). The RMSEs obtained from the later session (Session 8, 10, 11 respectively) were used for the first criterion categorization. The .02 RMSE criterion categorization was chosen because it was the largest

deviation from the standard with which subjects would still be able to earn a bonus. Subjects can be categorized into one of four groups represented by the four cells in the middle diagram in Figure 12. The labels A-D correspond respectively to the most optimal cell (A), the optimal average performance cell (B), the optimal coherence measures cell (C), and the least optimal cell (D).

On the whole, the number of subjects in the least optimal cell was reduced after some practice with the priority instructions and even with the secondary task difficulty increase. The number of subjects in the optimal cell at the same time increased slightly towards the end of the experiment. The change in the distributions of the number of subjects in each of the four cells is tested.

The number of subjects in each of the four cells were collapsed over all five dual-task conditions. The resulting distributions for each of the three manipulations are represented by the three columns displayed on the top of Figure 12. Chi-square tests for two multinominal distributions (see for example, Hogg & Tanis, 1977) were performed to test the equality of the subject distribution between the columns in Figure 12. The distribution in the left column was found to be significantly different from that in the middle column ($\underline{q}$ (3) = 11.94, $\underline{p} < .01$), and from that in the right column ($\underline{q}$ (3) = 8.21, $\underline{p} < .05$). The distribution in the middle column was however not reliably different from that in the right column ($\underline{p} > .1$). These chi-square results confirmed the observation that the distribution of subjects in each of the four cells had shifted significantly with the introduction of the priority instructions, but did not change further with the increase of the secondary task difficulty.

At the end of the experiment, each subject of the AF group was interviewed and was asked to describe the allocation strategy(ies) they employed to performed the time-shared tasks. There were two typical responses. One from those subjects who were quite successful in maintaining their average primary task RMSE at the standard level and one from those who were less able to do so.

The first group of subjects reported employing different strategies at different primary task difficulty levels, and particularly depended upon the primary task warning symbol and the tracking display to gauge their momentary primary task performance. The extent to which they worked on their secondary task depended upon whether their primary task performance was within a region of acceptable performance to the subjects themselves. Regardless of the secondary task performance level, these subjects reported that they would immediately concentrate more on the primary task whenever its performance was outside of their acceptable performance region. This latter comment suggested that subjects were employing a preemptive priority strategy: performing both tasks simultaneously (parallel processing) as much as possible, but as the primary task error increased, subjects behaved more like a single channel processor and concentrated on the high priority task. These strategy reports were quite different from those subjects who had difficulty maintaining their average primary task performance at the

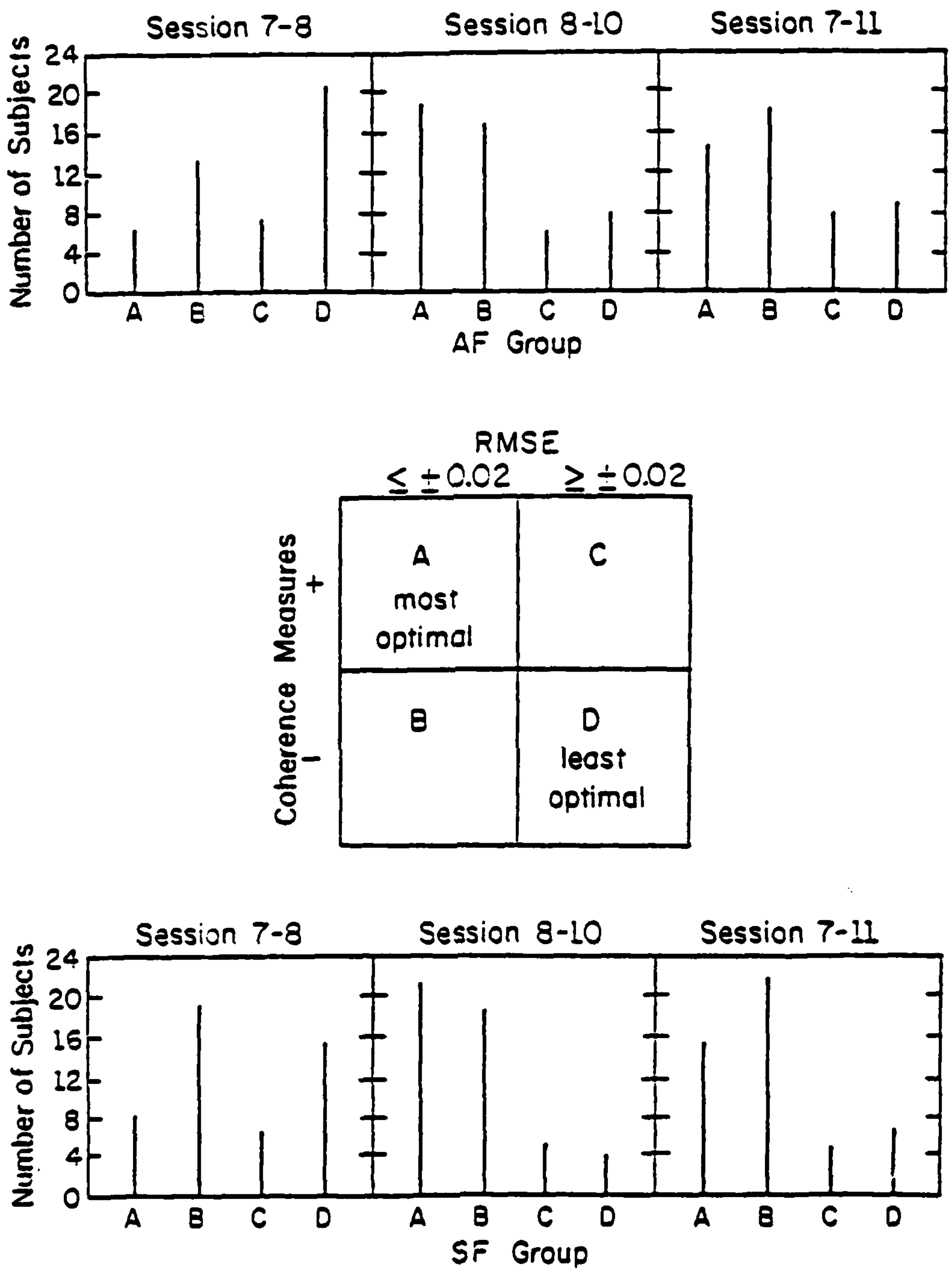


Figure 12: Categorization of subjects according to their ability to maintain the average primary task performance at the standard level (+/- <.02 RMSE) and to reduce the primary task coherence measures (+) in response to the priority instructions.

standard level. They reported using no particular strategy at all. They found the warning symbols distracting rather than helpful. Most of them reported difficulty in judging whether their moment by moment primary task performance was above or below their standards.

The lack of consistent strategies employed by the second group of subjects suggests that their allocation performance might be improved if they were provided with an effective strategy. However, reports from the first group suggest that there probably is not one "optimal" allocation strategy but a variety of strategies that are optimal under different conditions. The essence of optimality seems then to lie in the flexibility of behavior and the ability to employ a variety of strategies according to the changing task demands. A necessary precondition of such flexibility is the ability to discern that the task demands do change and call for different strategies. In light of the findings from the AF group, subjects in the SF group were particularly encouraged to make use of the primary task warning symbols. Subjects were instructed to perform the two tasks in parallel. However, as the primary task difficulty increased, they were to adopt a preemptive priority strategy and to abandon the secondary task entirely if necessary to protect the primary task performance. Instructions also emphasized that the secondary task was not to be abandoned in an indiscriminate fashion because bonuses could be earned with the secondary task performance as well.

Comparing the AF and SF groups. Subjects from the SF group were categorized in a similar manner as those from the AF group. The distributions obtained for each of the three columns are shown at the bottom of Figure 12. Chi-square tests were performed to test the equality of the distributions between columns. Results were similar to those obtained for the AF group. The distribution in the left column was reliably different from that in the middle column ($q\ (3) = 14.07$, $p < .01$) and from that in the right column ($q\ (3) = 6.74$, $p < .1$). Figure 12 clearly shows that the number of subjects in the most optimal cell has increased after practice with the priority instructions (middle column). Also, increase in the secondary task difficulty did not significantly alter the distribution already attained in Session 10.

The between-group difference for each of the five different task conditions was tested individually for each column. Results show that, after some practice with the priority instructions (middle column), the only reliable distribution difference between groups is in the dual-tracking condition ($q\ (3) = 8.62$, $p < .05$). Nine out of 10 subjects in the SF group were able to maintain their primary task performance within +/- .01 of their standards and the tenth within +/- .02 of his standard in the TR-TR condition. Furthermore, seven out of ten subjects in the SF group had their primary task coherence measures reduced. There were seven subjects in the optimal cell and none in the least optimal cell for the SF group in contrast to only three optimal subjects and four non-optimal subjects for the AF group.

Given the rather small degrees of freedom in the Chi-square distribution tests and hence a high probability of committing a Type II

error, the fact that the between-group difference was found only in the TR-TR condition and not in any of the STM-TR conditions is an important one. This between-group difference suggests that the strategy instructions were more effective for the TR-TR condition than the STM-TR conditions. The finding that the strategy instructions were differentially effective for the structurally different pairs of dual task reinforces the distinction between the two sources of allocation non-optimality: (1) skill deficiency that can be improved by training, and (2) structural limitations that cannot be improved by training.

The primary task performance data were also found to support the between-group difference. The SF group appeared to be able to maintain the average primary task performance slightly closer to the standard than the AF group under the dual tracking condition (Figure 1) as well as under the STM-TR conditions (Figure 4). The primary task performance for all five dual tasks (TR-TR and STM-TR) with two difficulty levels combined were not reliably different from the standard for the SF group ($\underline{t}$ (9) = 0.36, $\underline{p} > .1$). Those for the AF group on the other hand were significantly higher than the standard ($\underline{t}$ (9) = 2.09, $\underline{p} < .1$).

Summary. While the performance data suggest that the SF group was better able to maintain the primary task performance at the standard level than the AF group, the between-group difference was not large. The most significant effect with the strategy instructions manipulation is perhaps the finding that the strategy feedback appeared to be particularly helpful for the TR-TR condition. That the strategy instructions were more successful in improving allocation optimality for the task pairs having similar task structures than those with dissimilar task structures reinforces the distinction between a skill-based factor and a structural factor in determining the level of allocation optimality achieveable.

Discussion

The topic of the present paper is human control of attention allocation. A distinction was made between two aspects of time-sharing performance: time-sharing efficiency and attention allocation optimality. The first is concerned with the level of joint performance of the time-shared tasks. The second is concerned with the consistency of protecting the high priority task from variations in the task demand. Time-sharing performance was then evaluated as a function of : (1) the task structures of the component time-shared tasks, and (2) the strategy training of resource allocation.

The major findings are as follows. First, as predicted by the structure-specific resource model, a tradeoff between time-sharing efficiency and allocation optimality was observed. The tradeoff was defined by the degree of overlapping resources between the time-shared tasks. Results support the hypothesis that resource allocation is more optimal when the time-shared tasks place heavy demand on common processing resources than when they utilize separate resources. On the other hand, larger task interference was observed between time-shared tasks that compete for the same resources than those relying on

non-overlapping resources. Second, while considerable primary task error fluctuations around the standard were observed in the ensemble averages (see Figures 2 and 5-7), subjects were quite able to maintain the average primary task performance at the standard level. Third, subjects in the AF group were found to vary their strategies voluntarily for the different task conditions. Fourth, the strategy instructions appeared to be more effective in improving resource allocation optimality for the identically structured task pair (TR-TR) than the structurally dissimilar task pairs (STM-TR).

Significant implications of the present findings include the following. First, the current results reveal more clearly where the sources of allocation non-optmality might lie in the human information processing system. Second, while they are consistent with the multiple resource theory of attention, they also instigate a reexamination of the structural as well as the functional relationship between the various resources hypothesized in the structure-specific resource model. Third, the present results suggest several design principles that should be considered in a multitask environment. The sources of allocation non-optimality, the theoretical implications concerning the nature of the multiple resources, and the multitask design principles suggested by the current data will be discussed in turn below.

Findings from recent allocation studies (e.g., Brickner & Gopher, 1981; Wickens et al., 1979) tend to support the view that subjects do have voluntary, but often not optimal, control of attention allocation. Results of these studies together with the present data reveal that there are three broad categories of sources of allocation non-optimality: (1) those related to the subjects, (2) those related to the attention allocation mechanism, and (3) those related to the structural composition of the time-shared tasks.

Sources of Allocation Non-Optimality Related to the Subjects

Sources of non-optimality related to the subjects involve variables that the human has control of. There are three identifiable sources of this type: (1) difficulty in evaluating the momentary discrepancy between performance and task demand as suggested by Kahneman (1973), (2) failure to use the appropriate strategy, and (3) effectiveness of allocation training.

Difficulty in the demand evaluation process. A common techniuqe researchers employ to minimize difficulty in evaluating the momentary discrepancy between actual performance and task demand is to provide on-line as well as off-line performance feedback to the subjects. Results from previous research have shown that the on-line feedback is not always effective (e.g., Brickner & Gohper, 1981; Wickens & Pierce, 1978). In the present study, subjects' strategy reports revealed that not all of the subjects made use of the on-line feedback. Those who utilized the warning symbols found them helpful for gaugeing the momentary tracking performance but not for the memory task performance. It is possible that subjects did not rely on the warning symbol for accuracy information because an error in the running memory task would be immediately obvious to the subjects. Also, although the precise

reaction time would be less apparent to the subjects, the delay (averaging performance of the past five stimuli) and the cluster of information (combined speed and accuracy scores) could render the warning symbol too difficult to interpret in order to use effectively.

The differential usefulness of the warning symbols for the tracking and memory tasks coupled with the fact that those who reported using the tracking warning symbol were generally better able to maintain the average primary task performance at the standard level, suggest that on-line performance feedback could be helpful for resource allocation, but only if the feedback provides useful information and if the subjects utilize the information. Thus, the question of what exactly constitutes helpful information for resource allocation and how this information might be communicated to the subjects should be explored.

Failure to use the appropriate strategy. The recognition that a possible strategy for performing the task at hand exists and the refinement of the strategy used are two stages of skill postulated by Welford (1978). Indeed, those subjects in the AF group who had difficulty maintaining the average primary task performance at the standard level could not report using any strategies. It would seem that providing these subjects with an appropriate strategy would help them to reach at least the first stage of skill. However, the between-group comparisons of the level of allocation optimality achieved showed that the strategy feedback was not conclusively successful except for the dual tracking condition. Thus, it seems that it is in the second stage of skill that subjects failed.

As discussed earlier, the major components of allocation optimality lie in the flexibility of behavior and the ability to discern that the task demands do change, within a trial as well as across different task conditions. Failing to perceive that the changing task demand calls for different strategies and thus failing to modify the strategy provided accordingly could be a source of non-optimality. In fact, Moray et al. (1982) observed that when the difficulty of a monitoring-control task was increased, many operators persevered with a previously successful strategy in the easier condition even though it was clearly ineffective. Thus, in addition to seeking useful on-line performance feedback, ways of conveying to subjects the critical task features that would determine the appropriate strategy need to be explored.

Effectivenss of allocation trainiing. The finding that the strategy instructions were more beneficial to resource allocation training when the time-shared tasks utilize common resources than when they rely on separate resources may imply that resources between certain structures are not allocatable. Resource allocation optimality between these structures cannot therefore be easily improved by training. It is however important to note that even with the identically structured task pairs (TR-TR), attention allocation for the SF group was not optimal. Figure 3 shows that although the primary task coherence measures were reduced over the sessions, they remained consistently higher than those of the secondary task. Several possible reasons can be offered to account for the weak effects associated with the strategy instructions manipulation.

First, it is possible that two sessions (Sessions 9 and 10) did not allow subjects sufficient time to develop their strategies to the extent that would improve resource allocation. Thus, manipulating the amount of practice would be worthwhile in future research to determine the practice effects on the strategy instructions success in training resource allocation. Second, although all the subjects in the SF group were informed of the optimal strategy, only those subjects who continued to be unable to maintain the primary task performance at the standard level were continuously encouraged to adopt the optimal strategy. The small number of subjects that received vigorous strategy training may have diluted the effects of the strategy instructions manipulation. Third, only one strategy was provided for the subjects in the SF group. The strategy used was selected on the basis of a rather small sample of subjects (only those subjects in the AF group who were able to describe the strategies they employed). It is possible that the strategy selected may not truly reflect the most optimal strategy that can be provided for the SF group. In addition, regardless of whether the chosen strategy was truly the most optimal strategy, it is unlikely that the same strategy would be equally effective for all individuals (Rigney, 1978). Therefore, it may be helpful to provide subjects with a repertoire of strategies and allow each subject to choose his own strategies. To be able to provide subjects with a repertoire of strategies, systematic research effort will be needed to identify the possible allocation strategies employed by the subjects.

Sources of Allocation Non-Optimality Inherent in the Allocation Mechanism

According to the structure-specific resource model, resources pertinent to the different task structures may not be exchangeable. Such a view is inconsistent with Kahneman's conceptualization of a single closed feedback loop for resource allocation. More compatible with the concept of multipe resources is the view that there may not be one, but as many feedback loops as the number of meaningfully distinguishable resources. In fact, the present data together with those from other related studies suggest that while resource allocation between tasks competing for the same resources may involve a contiuous process through a closed feedback loop mechanism, allocation between tasks demanding primarily separate resources may be carried out in discrete units through an open loop mechanism.

The observation that attention allocation is generally more optimal when task demands are manipulated between trials at discrete levels than when they are manipulated continuously within a trial (e.g., Wickens & Gopher, 1977 vs. Wickens & Pierce, 1978) supports the notion that attention allocation is regulated through an open loop mechanism. That is, a fixed amount of attention to be allocated to each of the time-shared tasks can be determined at the beginning of each trial. On the other hand, from the present experiment, the interaction of the primary and secondary tasks linear coherence measures observed in the identically structured task pair (TR-TR) shows that resources were being shunted back and forth between the two tasks during the trial. Further, the presence of the sharp error spikes in the STM-TR error ensembles (Figures 5 and 6) but not in the TR-TR error ensembles (Figure 2) in the very first session that the priority instructions were introduced

suggests that allocation between the TR-TR task pairs was more continuous than that between the STM-TR task pairs.

One important distinction between a closed and an open feedback loop operation is particularly relevant to the present discussion. While a continuous closed loop control is highly dependent upon the moment by moment input, an effective open-loop control relies much more on the precise knowledge of the relationship between the input and the response prior to the execution of the control. One way to further test the distinction between a closed and an open loop allocation mechanism would be to require subjects to perform various task pairs that differ systematically in their structural configurations, with various degrees of predictability of the time course of the difficulty function. While a continuous closed feedback loop is less likely to be affected by the difficulty predictability, a discrete open loop control will be adversely affected by a high degree of unpredictability. Further, since different allocation mechanisms may be employed by different task structures, whether the degree of allocation optimality will vary as a function of the difficulty predictability may depend on the specific structural dimensions along which the component time-shared tasks differ. This is because while an open loop control should improve with increasing knowledge of the relationship between the input and the response which can be acquired through practice, no amount of training will be able to improve the allocation optimality between non-sharable resources. Even though a definitive model of the attention allocation mechanism cannot be offered at this point, the current findings suggest that Kahneman's initial conceptualization of the human attention allocation system may be incomplete. The hypothetical model discussed here may only be one of the many alternatives that awaits empirical testing.

Sources of Allocation Non-Optimality Related to tne Tasks

The effects of task structures observed in the present study confirm the hypothesis that resource allocation is more optimal whereas task are time-shared less efficiently when the time-shared tasks rely on common processing resources than when they place heavy demand on separate resources (see Table 1). That the extent of task interference increases as the degree of overlapping resources between the time-shared tasks increases is indicated by the finding that performance of both the primary tracking error (Figure 4) and secondary RT decrements (Figure 10) of those task pairs having two manual responses were in general poorer than those having one manual response and one speech response. This finding is congruent with a common finding in the dual task literature. Increase in allocation optmality with increasing shared resources was suggested by the decreasing trend of the primary task coherence and the increasing trend of the secondary task coherence measures observed in the TR-TR condition (Figure 3), but not in the STM-TR conditions (Figure 9). More convincing support was provided by the spike analysis (Figure 8) and the RT analysis (Figure 11).

Analysis of the RTs obtained at the instances that the primary task error spikes occurred shows that the RTs did increase with the level of the primary task difficulty even in the speech conditions where the

error spikes were most prominent and persistent. This result would argue that resources were being withdrawn from the secondary task at the instances that the primary task difficulty increased, implying an attempt on the subject's part to preserve the primary task performance. However, the persistent primary task error spikes in the speech conditions showed that resources that were withdrawn from the secondary task somehow did not benefit the primary task sufficiently to prevent the transient error spikes. Two possible explanations can be offered for this phenomenon. The first one is related to a perceptual difficulty in monitoring the constant changes in the task demands of the time-shared tasks. The second one is related to a response difficulty in delivering resources to the task that needs those resources.

The transient nature of the error spikes may reflect a difficulty in detecting the difficulty increases when the time-shared tasks utilized separate resources. Ignorant of the increase in the primary task difficulty, the subject continues to time-share as before until the primary task error builds up to a level that the subject finally notices the difficulty increase. If only a perceptual difficulty is involved, resource allocation should be possible once the increase in the primary task difficulty is detected. The decreased primary task error and increased RT obtained while alpha was still high, after the initial error spikes, seem to support the perceptual difficulty explanation.

The second explanation is response related. It is possible that while resource allocation between tasks demanding common resources (TR-TR) can be modulated in a continuous smooth fashion, resource allocation between separate stages/codes of processing but within a common output modality (VM-TR and AM-TR) may have a more discrete nature. Even though the subject may very well be aware of the difficulty increase and tries to transfer resources to the primary task (thereby causing the RT to increase), resources could not be successfully delivered in time from one stage/code of processing to another. As a result, the primary task performance was disrupted as alpha increased for the VM and AM conditions. With sufficient training however, allocation of resources between tasks of this sort can be accomplished (reduction of error spikes in Session 10). In contrast, continuous allocation between separate output modalities (VS-TR, AS-TR) does not appear to be amenable to training; perharps suggesting a non-sharable property between resources of different output modalities. Based on the present data, the two explanations just presented are equally plausible. In fact, they need not be mutually exclusive. For example, both may have the same underlying determinants -- that of some structural limitations.

Implications for the Nature of Multiple Resources

The most salient effect obtained in the present study is the structural effects. As illustrated in Table 1, the component time-shared tasks in the TR-TR pair and the VM-TR pair employed the same I/O modalities and differed only in the stages and codes of processing required of the component time-shared tasks. The error spikes present in the VM-TR but not the TR-TR conditions when the priority instructions were first introduced suggested that resource allocation was less

optimal in the VM-TR case because different stages and codes of processing were required. Whether the differential optimality observed is a result of separate stages or separate codes of processing cannot be determined here because the memory and the tracking tasks differed in both of these resource-defining dimensions. Nevertheless, the present results support the notion that either the stages of processing, the codes of processing, or both together are meaningful dimensions by which separate resources can be distinguished. Such a notion is also compatible with the finding of Friedman, Polson, Dafoe, and Gaskill (1982) that two tasks sharing the same stage, but distinctly different codes (defined hemispherically) failed to show any graded allocation effects, even with between trial manipulations.

The component time-shared tasks of the four I/O variations of the STM-TR tasks differed not only in their demand for resources of different stages and codes of processing, but also differed in their demand for resources of different I/O modalities. A clear differential practice effect was observed in the primary task ensemble averages between the two STM-TR tasks that employed a manual secondary response (VM-TR, AM-TR) and the two others that employed a speech secondary response (VS-TR, AS-TR). Most interestingly, even though the AM and VS tasks each had one common I/O modality with the primary tracking task (see Table 1), subjects were much better able to protect the primary task performance against the momentary difficulty increase under the AM-TR condition than the VS-TR condition by the end of the experiment. While the differential output effect was further substantiated by statistical analysis of the error spikes, the same analysis did not reveal any reliable differences between the two input modalities. These data may imply that allocation optimality does not necessarily depend only on the number of shared resources the component time-shared tasks have in common, but also on the specific resources that they each place heavy demand on.

The present data are not only compatible with the multiple resource concept of attention, they support the structure-specific resource model's hypothesis that the stages, codes, and I/O modalities of processing are meaningful dimensions along which resources may be separated. Further, the present results suggest that the various separate resources may not be all equally distinct. For example, the difference observed in the primary task ensemble averages for the TR-TR and STM-TR task pairs (sharp error spikes in the STM-TR but not in the TR-TR conditions) suggest that the different stages/codes of processing may have separate but partially sharable resources (hence the error spikes could be reduced with practice for the VM and AM conditions). While resources associated with the different inputs are probably quite exchangeable (since the input effect in the various statistical analyses were largely insignificant), resources associated with different the output modalitiess are probably functionally more distinct (hence the error spikes persisted in the VS and AS conditions). Thus, it can be argued from the present data that there is a continuum of separability between the different processing resources rather than a simple dichotomy of separate vs. common resources. It is conceiveable that instead of a continuum, the various levels of separability can be

organized in a hierarchical manner as proposed by Wickens (1981). At present, little is known as to what really distinguishes the separate resources. Three candidates alluded above were: (1) separate resources use separate feedback loops for attention allocation; (2) separate resources may render the monitoring task of evaluating the momentary task demands more difficult; (3) separate resources may be allocated in different units, for example, continuous versus discrete chuncks. Much research effort will be needed to reveal more clearly the intricate relationships between the different resources.

Implications for Task Designs.

The systematic structural effects observed on time-sharing efficiency and resource allocation optimality suggest that the structural configurations of the time-shared tasks would be an important factor from which time-sharing performance can be predicted. Within the framework of the structure-specific resource model, the stages of processing required of a task usually cannot be changed without altering the task itself. However, task designers sometimes have the freedom to assign either spatial or verbal codes of processing to the tasks. Furthemore, given the recent adavancement in visual displays and speech technology, switching the input/output modalities in order to facilitate time-sharing performance is often quite feasible.

The current findings suggest that in order to achieve a high degree of time-sharing efficiency, the time-shared tasks should be designed to minimize task interference by combining tasks that utilize as many separate resources as feasible. But, since resource allocation appeared to be more optimal with an increasing degree of shared resources between the time-shared tasks, the very task configuration that would theoretically yield the highest time-sharing efficiency will also impede optimal resource allocation. Given that time-sharing efficiency is always desirable, task designers would have to evaluate the importance of being able to maintain a constant performance of the high priority task, regardless of the changes that may occur in the level of task demands. A possible scenario where a constant performance is crucial may be having to maintain a hovering helicopter at a certain altitude (constant performance) under adverse weather conditions (entailing unpredictable wind gusts, i.e., continuously changing task demands) in order to carry out a rescue mission. Under such circumstance, design for resource allocation optimality, and not just for time-sharing efficiency, seems warranted.

Conclusions

Three broad categories of the sources of resource allocation non-optimality were identified in the present study. Even though they were discussed separately, they are not as unrelated as they might first appear to be. For example, the mechanims of allocation control clearly depend to a great extent upon the functional and structural organization of the processing resources. The trainability of allocation skill and the effectiveness of strategy instructions in particular would also depend on the degree that the various functionally or structurally distinct resources are sharable. While the present data seem to have

provided us with a better understanding of the sources of attention allocation non-optimality that could account for certain time-sharing deficiency, they collectively point to our present incomplete understanding of the true nature of processing resources. It can be concluded from the data that while the concept of multiplicity of resources is still accurate, much continued research effort will be needed to reveal the intricate relationship between the meaningfully distinct resources.

References

Baron, J. Intelligence and general strategies. In G. Underwood (Ed.), Strategies of Information Processing. New York: Academic Press, 1978.

Brickner, M. & Gopher, D. Improving time-sharing performance by enhancing voluntary control on processing resources. Israel Institute of Technology, Research Center for Work Safety and Human Engineering, Technical Report AFOSR-77-3131C, February, 1981.

Chatfield, C. The Analysis of Time-Series: Theory and Practice. London: Kendall, 1973.

Friedman, A., Polson, M. C., Dafoe, C. G., & Gaskill, S. J., Dividing attention within and between hemispheres: Testing a multiple resources approach to limited-capacity information processing. Journal of Experimental Psychology: Perception and Performance, 1982, 8(5), 625-650.

Gopher, D. & Navon, D. How is performance limited: Testing the notion of central capacity. Acta Psychologica, 1980, 46, 161-180.

Hogg, R. V. & Tanis, E. A. Probability and Statistical Inference. New York: MacMillan, Inc., 1977.

Israel, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. P300 and tracking difficulty: Evidence for multiple resources in dual task performance. Psychophysiology, 1980, 17, 57-70.

Kahneman, D. Attention and Effort. Englewood Cliffs, NJ: Prentice Hall, 1973.

Kantowitz, B. H. & Knight, J. L. On experimenter-limited process. Psychological Review, 1976, 83, 502-507.

Kerr, B. Processing demands during mental operations. Memory and Cognition, 1973, 1 , 401-412.

Miller, G. A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review, 1956, 63, 81-97.

Moray, N. The strategic control of information processing. In G. Underwood (Ed.), Strategies of Information Processing. New York: Academic press, 1978.

Moray, N., Fitter, M., Ostry, D., Favreau, D., & Nagy, V. Quarterly Journal of Experimental Psychology, 1976, 28, 271-285.

Moray, N., Sanderson, P., Shiff, B.,Jackson. R., Kennedy, S., & Ting, L. A model and experiment on the allocation of man and computer in supervisory control. IEEE Proceedings of the International Conference on Cybernetics and Society, Seattle, 1982.

Navon, D. & Gopher. D. On the economy of the human processing system. Psychological Review, 1979, 86, 214-255.

North, R. A. Task components and demands as factors in dual-task performance. Savoy, IL: University of Illinois at Urbana-Champaign, Institute of Aviation, Aviation Research Laboratory, Technical Report ARL-77-2/AFOSR-77-2, January, 1977.

Ogden, G., Levine, J., & Eisner, E. Measurement of workload by secondary tasks. Human Factors, 1979, 21(5), 529-548.

Rigney, J. W. Learning strategies: A theoretical perspective. In H. F. O'Neil, Jr. (Ed.), Learning Strategies I. New York: Academic press, 1978.

Rolfe, J. The secondary task as a measure of mental load. In Singleton, Easterby, and Whitfield (Eds.), Measurement of Man at Work. London: Taylor & Francis, 1971.

Senders, J. The human operator as a monitor and controller of multi-degree-of-freedom systems. IEEE Transactions on Human Factors in Electronics, 1964, HFE-7, 103-106.

Singer, R. N. Motor skills and learning strategies. In H. F. O'Neil, Jr. (Ed.), Learning Strategies. New York: Academic Press, 1978.

Welford, A. T. Mental workload as a function of demand, capacity, strategy, and skill. Ergonomics, 1978, 21(3), 151-167.

Wickens, C. D. The structure of attentional resources. In R. Nickerson & R. Pew (Eds.), Attention and Performance VIII, Englewood Cliffs, NJ: Lawrence Erlbaum, 1980.

Wickens, C. D. Processing resources in attention, dual task performance and workload assessment. University of Illinois, Engineering Psychology Research Laboratory, Technical Report EPL-81-3/ ONR-81-3, July, 1981.

Wickens, C. D. & Gopher, D. Control theory measures of tracking as indices of attention allocation strategies. Human Factors, 1977, 19, 349-366.

Wickens, C. D. & Pierce, B. Linear modelling of attentional resource allocation. Proceedings, 14th Annual Conference on Manual control, 1978.

Wickens, C. D., Sandry, D., & Vidulich, M. Compatibility and resource competition between modalities of input, central, processing, and output. Human Factors, 1983, 25(2), 227-248.

Wickens, C. D. & Tsang, P. The dynamics of resource allocation. University of Illinois Engineering Psychology Research Laboratory, Technical Report EPL-78-3/AFOSR-78-3, June, 1979.

Wickens, C. D., Tsang, P., & Benel, R. The dynamics of resource allocation. Proceedings, 23rd Annual Meeting of the Human Factors Society, Santa Monica, Human Factors Press, 1979.

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(Figures 5 and 6) but not in the TR-TR error ensembles (Figure 2) in the very first session that the priority instructions were introduced

END

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